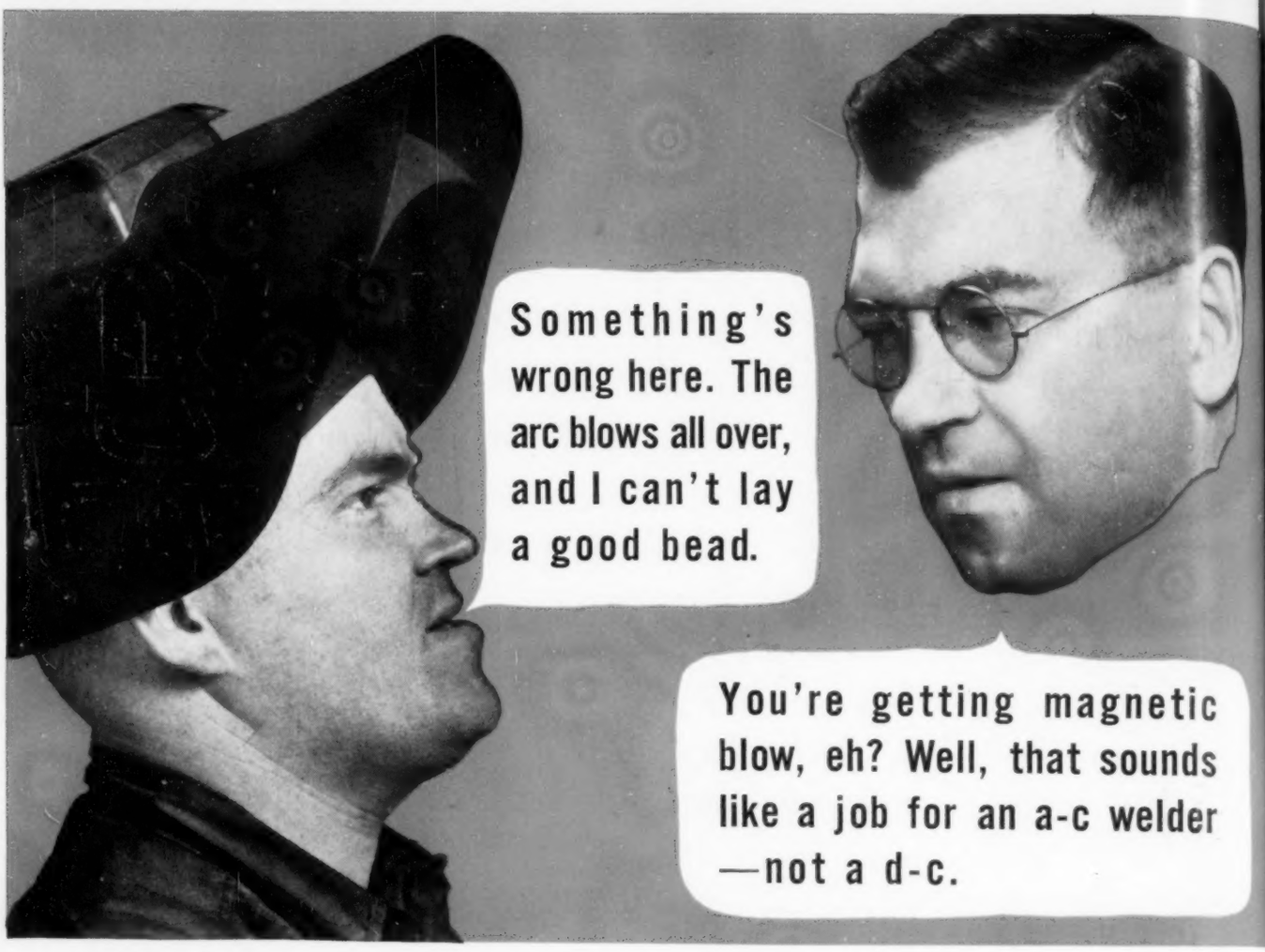
The Welding Journal

The Journal of the American Welding Society


Something's wrong here. The arc blows all over, and I can't lay a good bead.
You're getting magnetic blow, eh? Well, that sounds like a job for an a-c welder —not a d-c.

AND he's probably right! An increasing number of fabricators are changing to G-E alternating-current welders because of the better results obtained on certain types of work.

WHERE . . . G-E alternating-current welders can be used profitably in the fabrication of heavy machine frames, pressure vessels, high-pressure piping, penstocks, refining vessels, steam boilers, and similar work. They can also be used to advantage in light-gauge welding.

WHY. . . Troublesome magnetic blow is avoided, thus permitting heavier currents and increased speeds. Quality is improved because of the refining action of the a-c arc. On light-gauge work, the decreased penetration helps prevent "burn-through."

WHAT. . . G-E a-c welders are available in sizes of 150, 300, 500, 750, and 1000 amperes, each of which provides a wide continuous range of welding current. They are safe, dependable, and save up to 50 per cent in power costs compared with the rotating type of a-c machine.

HOW. . . Learn more about this remarkable line of welders by consulting the nearest G-E arc-welding distributor or the nearest G-E sales office. They'll be glad to help you decide whether you have a profitable application for a-c welding. Or fill in the coupon and send it to General Electric, Schenectady, N. Y.

TO GIVE YOU THE RIGHT WELDING EQUIPMENT, GENERAL ELECTRIC MANUFACTURES THE MOST COMPLETE LINE OF ARC WELDERS IN THE WORLD.

General Electric
Dept. 6C-201, Schenectady, N. Y.

☐ Please send me Bulletin GEA-1750C, on a-c welding.

☐ Can I use a-c welders to advantage in my work? (Attach description of work.)

NAME .....

FIRM .....

STREET .....

CITY ..... STATE .....

GENERAL ELECTRIC

Filing No. 8748

Engin.
Library

The AMERICAN Welding Journal SOCIETY

W. SPRARAGEN, Editor

OFFICERS—1937-1938

President, P. G. LANG, Jr.
Treasurer, C. A. McCUNE
Senior Vice-President, Col. G. F. JENKS
Secretary, M. M. KELLY
Managing Director, WARNER S. HAYS
Technical Secretary, W. SPRARAGEN

Divisional Vice-Presidents

J. H. ZIMMERMAN, New York and New England
R. D. THOMAS, Middle Eastern Division
H. C. BOARDMAN, Middle Western Division
K. V. KING, Pacific Coast
W. J. SANNEMAN, Southern

PUBLISHED FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING

Vol. 17, No. 2 FEBRUARY 1938

CONTENTS

TECHNICAL PAPERS, ITEMS AND REPORTS

Welded Steel Building Combines Beauty and Utility, by *C. K. Priest* ... 3
World's Longest Horizontal Self-Supporting Pipe Span, by *A. F. Davis* ... 5
Selective Hardening with the Oxyacetylene Flame, by *R. L. Rolf* ... 6
Welding Economics and Application, by *E. W. P. Smith* ... 10
A Discussion on the Effect of Welded Top Angles on Beam-Column Connections, by *H. W. Lawson* ... 13
Arc Welding in the Construction of Heavy Steel Presses for Automotive Industry, by *L. L. Jacobs* ... 14
Carnegie-Illinois Steel Corp. South Works—No. 5 Power Station, by *A. C. Wilby* ... 15
Review of the Oxyacetylene Industry—1937, by *Dr. G. V. Slottman* ... 16
New Method Eliminates Stresses in Welding High-Pressure Piping, by *C. J. Holslag* ... 19
Important Uses of the Oxyacetylene Process in Steel Mill Operations, by *W. J. Sannemann* ... 20
Discussion of Paper Presented by V. Willoughby "Welding of Railroad Rolling Stock," by *Jules Muller* ... 22
Flame Hardening, by *John T. Howat* ... 23
Joining Copper Bus Bars with Brazing Alloys, by *R. A. Goeller* ... 26
Preheating Pipe, by *C. M. Weinheimer* ... 31
Silver Brazing Tubes to Tube Sheets, by *Leo Edelson* ... 32
Meeting an Emergency, by *George Sykes* ... 33
Repair on a Production Basis, by *Alan Kellock* ... 34
Steel Plate Fabrication in the Heavy Machinery Field, by *J. H. Cooper* ... 35
Standardization of Materials for Coated Electrodes, by *Gordon H. Chambers* ... 38

Cover

Flame Softening Facilitates Cutting Certain Steels

See Article by H. MOSS January 1938 Issue

Courtesy The Linde Air Products Co.

SOCIETY AND RELATED ACTIVITIES

Index to Advertisers ... 40
Western Regional Conference ... 41
Western Metal Congress ... 42
1938 Nominating Committee ... 43
Committee on Outline of Work ... 43
Representatives on Other Societies ... 43
Members Executive Committee ... 43
Board of Award ... 43
The William B. Pollock Company ... 43
International Engineering Congress ... 43
Progressive Welder Pamphlet ... 43
McKay-Arcos Co. ... 43
Photoelasticity, by *A. G. Solakian* ... 44
John A. Capp ... 44
Year Book Error ... 44
Albert Reichmann Retires ... 44
Riehle to Manage Welding Sales ... 44
Professor Wilson Honored ... 44
1938 Foundry Convention ... 44
Section Officers and Meetings ... 45
Section Activities ... 46
Employment Service Bulletin ... 47

ISSUED MONTHLY

Copyright, 1938, by the American Welding Society

Subscription to those not eligible for membership $5.00 per year in United States and possessions; $5.50 in Canada and Foreign Countries. Single copies, non-members $1.00, members 50 cents.

Entered as second-class matter January 15, 1932, at the post-office at Easton, Pa., under the Act of March 3, 1879.

PUBLICATION OFFICE
20th & Northampton Streets, Easton, Pa.

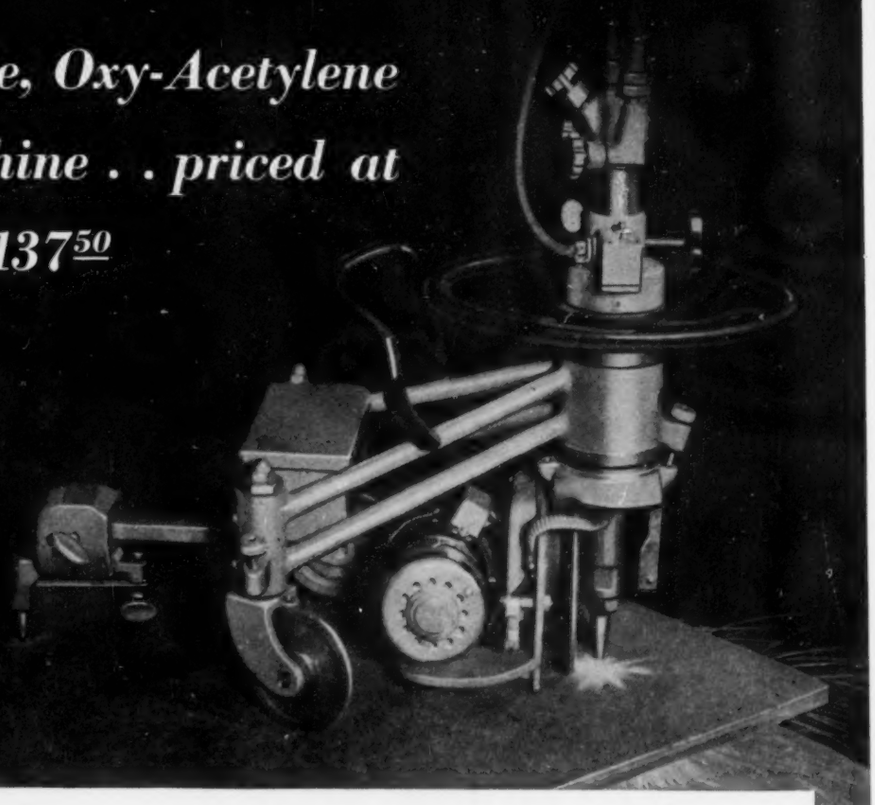
EDITORIAL AND GENERAL OFFICES
33 West 39th St., New York, N. Y.

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided proper credit is given.

The OXWELD CM-16

A dependable, Oxy-Acetylene Cutting Machine . . priced at

$137.50



An oxy-acetylene cutting machine is now available at a price which enables every steel fabricating shop to take advantage of the economies of cutting steel to shape by machine. The Oxweld CM-16—newest of a complete line of portable and stationary machines—now costs only $137.50†. Yet it has a wider cutting range and is easier to operate than any comparable machine. The CM-16 can cut straight lines and circles automatically in steel plate up to four inches thick. It can be guided by hand and, since it weighs only 45 pounds, it is particularly convenient for shaping irregular parts, or when it is necessary to carry the machine from job to job.

A Linde representative will gladly give you the story complete in all detail. For descriptive literature, write the Linde office nearest you. The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation, New York and principal cities.

†Price slightly higher west of Rocky Mountains

The word "Oxweld" used herein is a registered trade-mark

Everything for Oxy-Acetylene Welding and Cutting

LINDE OXYGEN • PREST-O-LITE ACETYLENE • OXWELD APPARATUS AND SUPPLIES FROM LINDE UNION CARBIDE

PRODUCTS OF UNITS OF UCC UNION CARBIDE AND CARBON CORPORATION

Welded Steel Building Combines Beauty and Utility

By C. K. PRIEST†

Fig. 3—Modern Daylight All Arc-Welded Steel Factory Building for the Fabrication of All Arc-Welded Steel Houses

TO GIVE additional space for the prefabrication of Arc-Welded Steel Houses, Hobart Brothers Company of Troy, Ohio, have recently completed a modern arc-welded steel factory. The new structure combines all the latest and modern ideas for comfort of worker, and ease of operation, with beauty seldom found in factory buildings. In many ways this new plant is unique and will, no doubt, create a new trend in factory building.

The general design consists of a large center bay forty feet wide by twenty-five feet high, flanked on each side by lower sections twenty feet wide and twelve feet high. (Fig. 1.)

† Hobart Brothers Company, Troy, Ohio.

Fig. 1—A Well-Lighted Interior Affords Comfortable and Pleasant Working Quarters the Year Round in This All Arc-Welded Steel Building

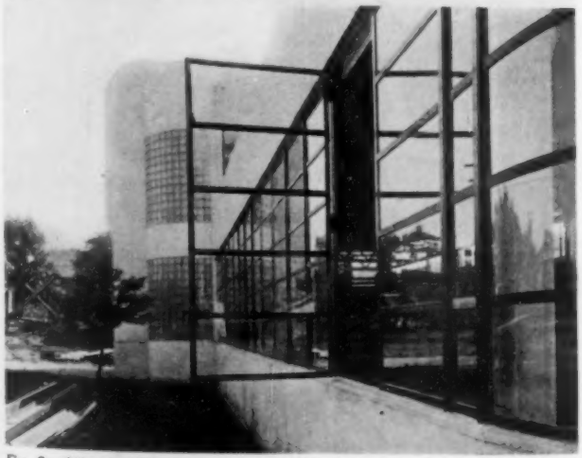


Fig. 2—Attractive Window Arrangement Gives the Effect of Continuous Glass Sections All Around the Building

At no point is there a bolt or rivet as the entire building is made integral by arc welding. Two-thirds of all vertical surfaces are clear glass or glass brick, insuring best daylight conditions.

If this is not the first, it is undoubtedly one of the first factories in the world to be completely insulated. This is accomplished by the use of welded steel panels, consisting of two sheets of steel spread apart by a steel strut. The insulation is packed in these panels and the whole assembled into the frame by the process of arc welding. Insulated side panels are four inches thick, and on the roof eight inches thick. This insures minimum heating cost in winter and maximum comfort to workers in summer. The insulation used in the walls and roof is the equivalent of a thirty-inch brick wall, in so far as heat passage is concerned. Insulation of houses is now an accepted improvement and is just as desirable in factory building.

As this was, in many ways, a pioneer type of building, all parts were fabricated from the formed steel in the company's steel-house shop and erected by the same group. All trusses, panels, windows and small parts were welded into sub-assemblies and passed on to erection crews who welded them into their final positions, exactly as a steel house is now prefabricated in the finished factory.

The type of window developed is new in many respects. Each window is three by seven feet with five horizontal glasses in each. Each window was made to abut adjacent window without mullions between, giving the effect of continuous glass sections all around the building. Corners were made round with continuous curved glass, giving a very pleasing and modernistic exterior effect. One-third of the windows are hinged on the side and the opening controlled by an opening and closing device to

Fig. 4—Arc Welding Standard Channel and Angle Steel Forms Frame Work for Modern All Arc-Welded Steel Daylight Factory Building

Fig. 5—Some of the Welded Hobart Steel Houses

1—Six Room All Arc-Welded Steel Georgian House Enroute to Foundation in Hobart Circle

2—The Regency House, 6 Rooms and Bath All of Arc-Welded Steel

3—"Hobart" House All Steel Arc-Welded, 5 Rooms and Bath

4—The "Cape Cod" House All Arc Welded Steel, 5 Rooms and Bath

5—The "White House" Show Place in Hobart Circle Where Ten Different Design Arc-Welded Steel Houses Are Erected

6—"White House" Living Room View of Arc-Welded Steel Showing Attractive Spiral Steel Stair Case and Glass Block

set the window at any desired point. As the windows are very large and open laterally rather than vertically, they can be set to serve as air scoops and force air through the building on warm days. To take advantage of prevailing breezes from any direction, alternate windows were hinged on opposite sides.

Specifications required overhead traveling hoists to lift heavy sections of steel houses in the central portion of the building. To obtain the strength necessary to lifting heavy loads, conventional type trusses were used overhead, continuously welded at all joints to obtain maximum strength.

The interior of the building was finished in glass white enamel, and this coupled with maximum light entrance from a large window area causes remarkably good natural lighting conditions, for manufacturing operations, and pleasant working conditions.

Although this factory is located in a residential district, no complaints are made. The appearance is such that it is a credit to the locality.

The treatment of the exterior is modernistic. The finish is snow white with seafoam green window trim. All corners are round, and all pylons and other trim are curved, causing a very unusual effect and one very pleasing to the eye. At one end of the building are conventional type doors for entrance of raw material. At the other end are airplane hangar type doors to permit the removal of a completed house. About midway is a domed, modernistic entrance for employees.

The most unique thing about this factory is the fact that it is the first one ever built for the manufacture of prefabricated houses. Prefabricated means completely assembled. The houses built in this factory are complete in every detail, completely decorated and painted, ready to be placed on a foundation. All that needs to be done is connect light, gas, water and sewer services, and the house is ready to live in. Although this factory is different in many respects, there is no arguing the point that the product is different and shall we say, welcome!

World's Longest Horizontal Self-Supporting Pipe Span

By A. F. DAVIS†

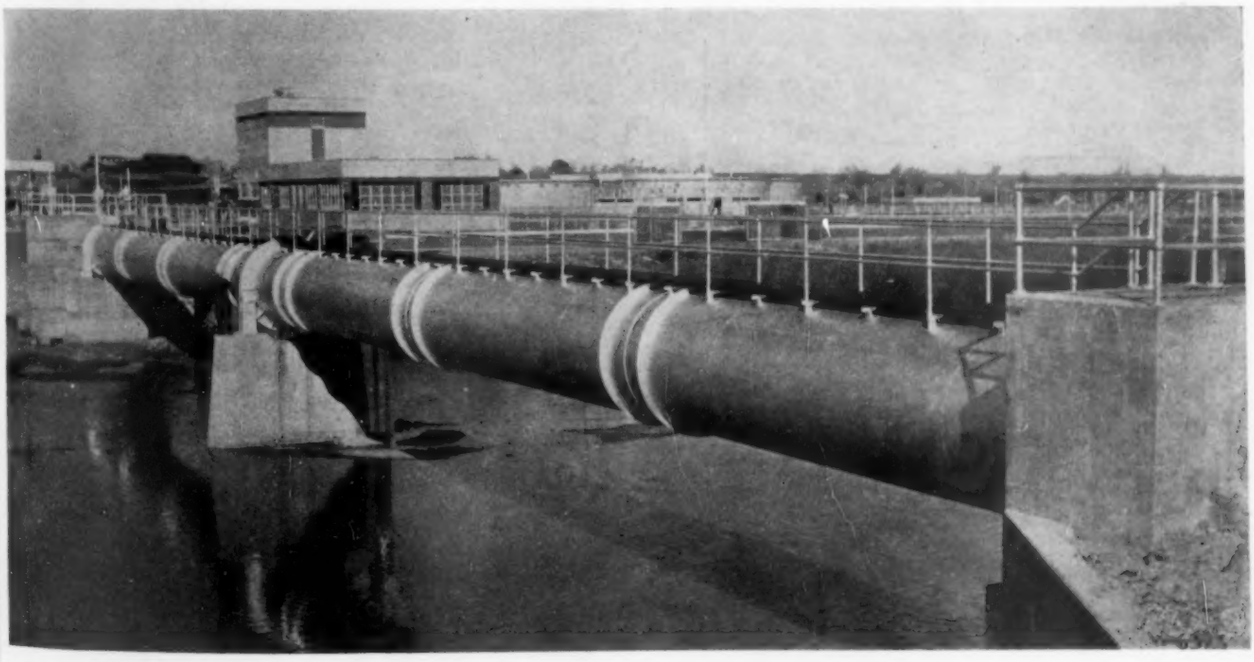
UNTIL the two spans of pipe shown in the accompanying illustration were constructed, a pipe span of a hundred feet was unheard of. The spans illustrated here are each 105 feet long. The structure carries sewage across the Platte River to the new sewage disposal works at Denver, Colorado. This is to be the longest unsupported span of pipe in the world. It was made possible by new theories in the design of supporting metal pipe which have led to use of a new method of construction. The principle involved in the construction of such long spans is that of preventing distortion at the points of support by welding stiffener rings to the pipe. These rings transmit the load to the foundation by means of legs attached to them. Use of the new method of construction demonstrated a saving in cost of 22% over the next most economical design, and offered less obstruction to flow inside the pipe. The welding was done by the shielded arc process.

The pipe is 78 inches in diameter, and ranges in thickness from $^5/_8$ inch to $1^1/_8$ inches. The stiffener ring at the center pier is a 12-inch 40-lb. I beam rolled edgewise. The legs on this ring are rigidly fastened to the center pier. The stiffener rings at the ends of the pipe are 10-inch 30-lb. I beams. The legs on these rings rest on patented rollers. An expansion joint in the wall at each end of the pipe allows it to expand both ways from the center. All seams were butt welded electrically.

The pipe was designed as a continuous structure for a maximum combined fiber stress of 9800 lb. per sq. in. in the pipe shell, and 16,000 lb. per sq. in. in the stiffener rings. Maximum negative bending moment at the center pier is 4,138,000 pound feet. It occurs at points 39 feet 4 inches from the end supports.

The pipe was designed, fabricated of copper molybdenum iron by electric welding and erected by the Thompson Manufacturing Company of Denver, Colorado.

† Vice-President, Lincoln Electric Co.



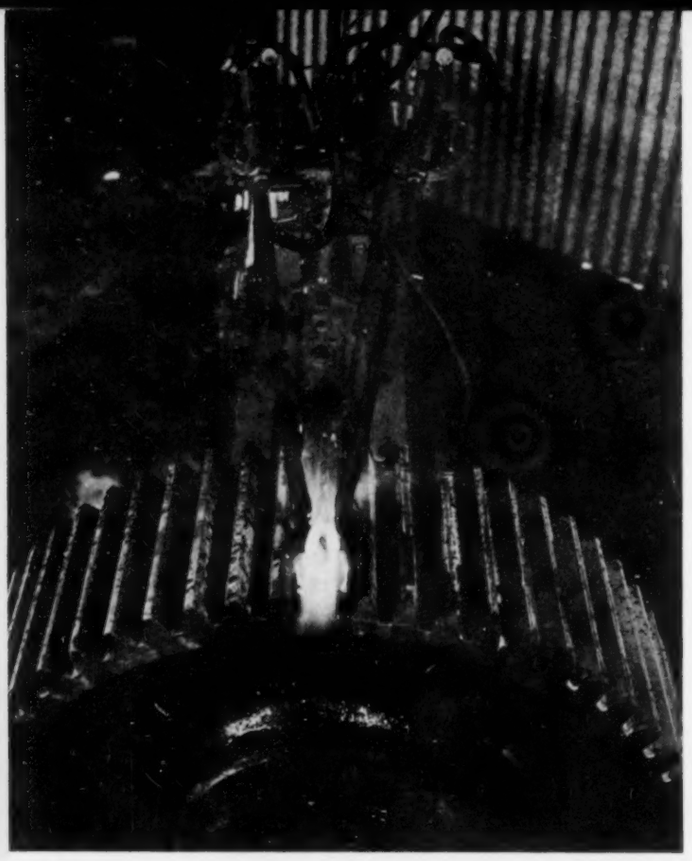


Fig. 1—Set-Up Used in Torch Hardening Spur Gears

SELECTIVE HARDENING with the Oxyacetylene Flame*

By R. L. ROLF†

EXTENSIVE commercial use of the oxyacetylene flame in the heat-treating industry has brought widespread attention to the possibilities of enlarging its scope in the manufacturing field.

With rapid development in equipment design, there appears to be no limit as to its application, and what only a short time past was considered an impossibility is today of wide commercial importance.

Manufacturers are proposing new parts or are making plans to convert present designs for adaptation to the process. In most instances the cost is lower than that of any other means of fabrication and the rejections are negligible.

With a new process, it is often common practice among those not familiar to draw erroneous conclusions as to its application for their particular problem.

Experience has shown that it is far simpler to secure enlightenment on these subjects by analysis of case histories than by any other means of approach, and bearing this in mind, the following cases are cited to illustrate how torch hardening may be applied with comparative ease, lending itself to both quality and quantity production.

Gears of all descriptions present an ideal application. Size or shape is no longer a problem. The design may be helical, spiral, bevel or spur. If they are small they may be hardened by the spinning method, while on the large units progressive hardening may be used.

A typical set-up for spur gears is illustrated in Fig 1. The twin torches heat and quench both sides of the tooth simultaneously, reducing time of operation and minimizing tooth distortion. Varying the speed from slow at the start to a more rapid finish insures uniformity of hardness and depth of penetration.

During the early stages of torch hardening it was impossible to obtain a uniform case depth on tapered teeth. When the torches were adjusted to the large end the small section would show a shallow case, as the torches moved only in one plane and once adjusted for the heavy end of the tooth, the flame and quench would be too far away at the small end to permit proper heating and quenching, or when designed to follow tooth contour it would result in overheating the small end.

† Metallurgical Engineer, Lakeside Steel Improvement Co.

* Presented at the 38th Annual Convention, International Acetylene Association, Birmingham, Alabama, November 10-12, 1937. Cuts loaned through courtesy *Steel*.

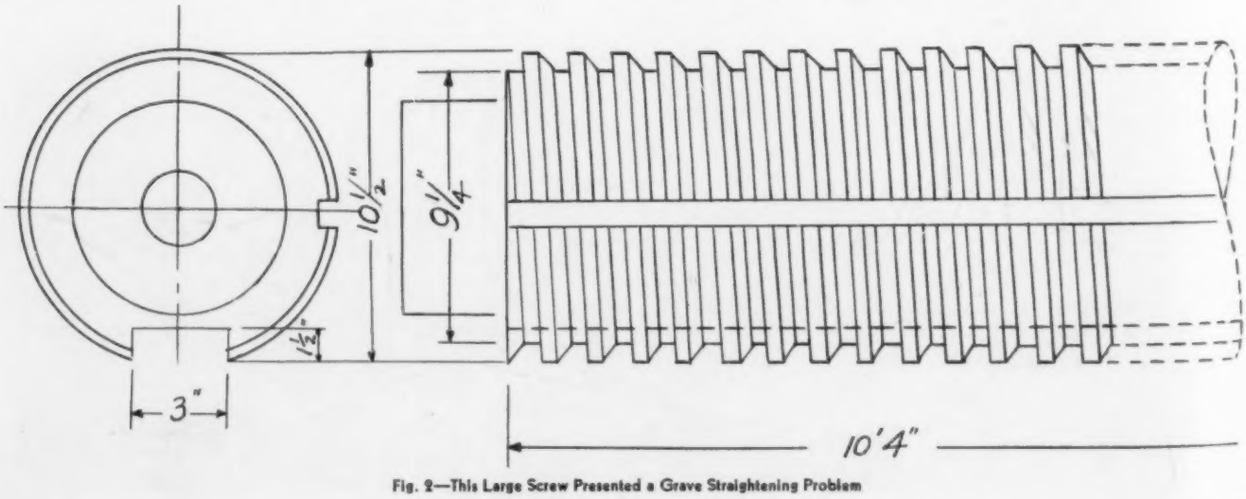


Fig. 2—This Large Screw Presented a Grave Straightening Problem

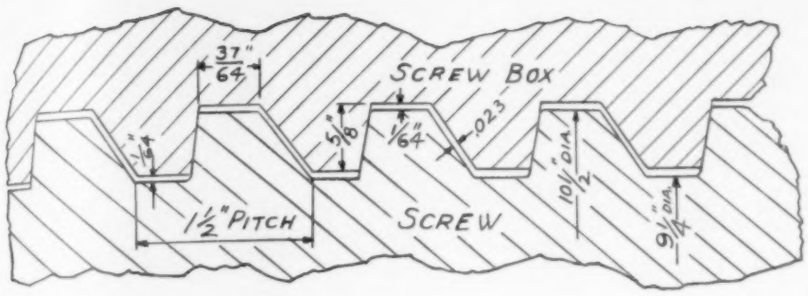


Fig. 3—Cross Section of the Nut and Screw Showing the Small Runout Permissible

Today, with an arrangement such as illustrated in Fig. 4, the torches are contracted or expanded automatically insuring the same relation between the work and the flame at any position of the tooth.

A leading manufacturer of heavy equipment found it was necessary to reduce wear on a large elevating screw and nut, which, due to distortion and close tolerances, were machined from untreated material and left in that state.

The screw, shown in Fig. 2 being 9 inches in diameter and 10 feet long, presented a grave straightening problem as the permissible runout was very small, as may be evidenced from the cross sections of both nut and screw, shown in Fig. 3.

Machining from heat-treated bar stock gave small additional life, but not sufficient to warrant the large increase in machining costs. Fabricating from a medium carbon alloy steel and flame-hardening would produce the necessary hardness and eliminate distortion, but this presented a new torch-hardening problem, for up to this time, work of this character had not been attempted.

A simple but ingenious set-up solved this problem. The screw was mounted in chucks and rotated by a variable-speed drive; the monitor carrying two small torches was mounted parallel to the screw. Coordinating the horizontal travel of the monitor with the rotation of the screw permitted this unit to be hardened uniformly for the entire length.

While the nut shown in Fig. 5 presented a problem of internal hardening, its similarity to the screw made the solution comparatively simple. This component was mounted on rollers and driven from one end by a variable speed drive. The torch monitor was mounted at the open end and a guide with one end attached to the monitor and the other in the nut thread automatically fed the torches through the nut. In this manner, both screw and nut were hardened to a Shore hardness of 8085 without scale or distortion, and this was the solution to the problem.

Worm threads present a difficult hardening problem, since the gradually increasing thickness of the lead, together with tooth form and depth, add complications to an already complicated situation.

With proper head design and camming action, satisfactory hardening may be achieved.

Worms should be fabricated from the low-carbon steels and carburized and hardened. However, there are cases where this is not essential and a plain heat-treated worm will suffice.

In such instances, if the core strength is not important, flame hardening may be substituted. For several years the worm shown in Fig. 6 was machined from a chrome vanadium steel of the S. A. E. 6150 grade and heat treated in the conventional manner. While core strength was not a prime factor, it was essential that the threads be hard. The specification called for Rockwell 50–55 C, which only permitted a draw of 400 degrees Fahr. after the quenching operation. Two keyways 180 degrees from each other added considerably to the distortion of the shanks, which could not be drawn back to permit easy straightening without reducing the hardness of the threads. The straightening costs and the scrap loss due to breakage during this operation were extremely high.

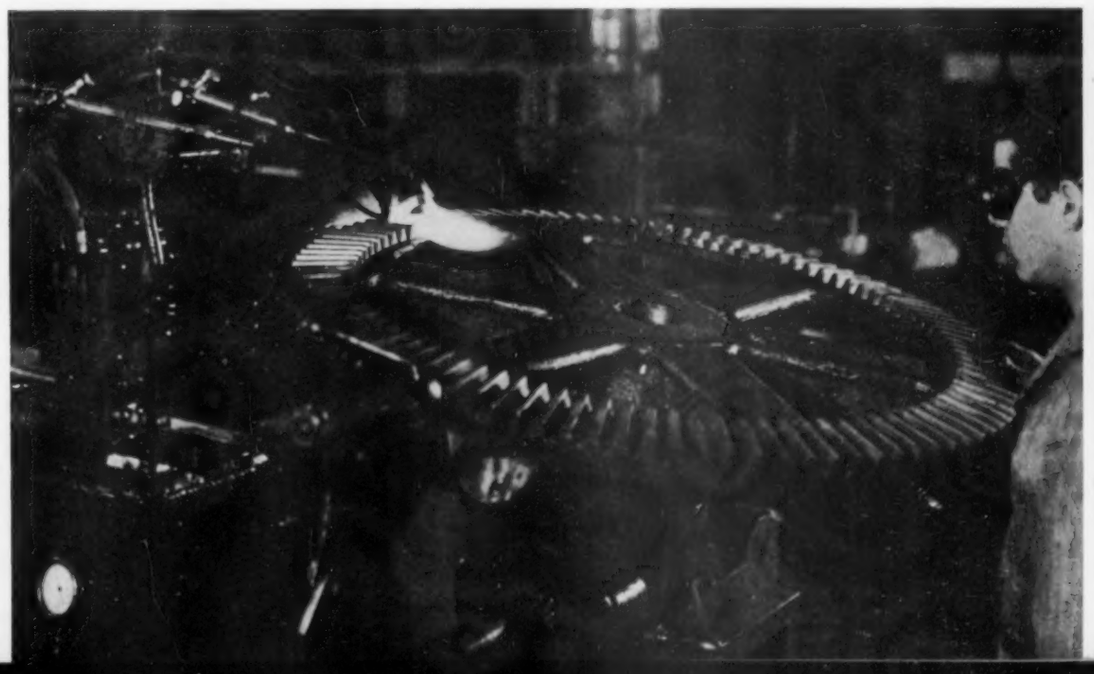


Fig. 4—This Machine Insures the Proper Relation Between Flame and Work in Gear Hardening

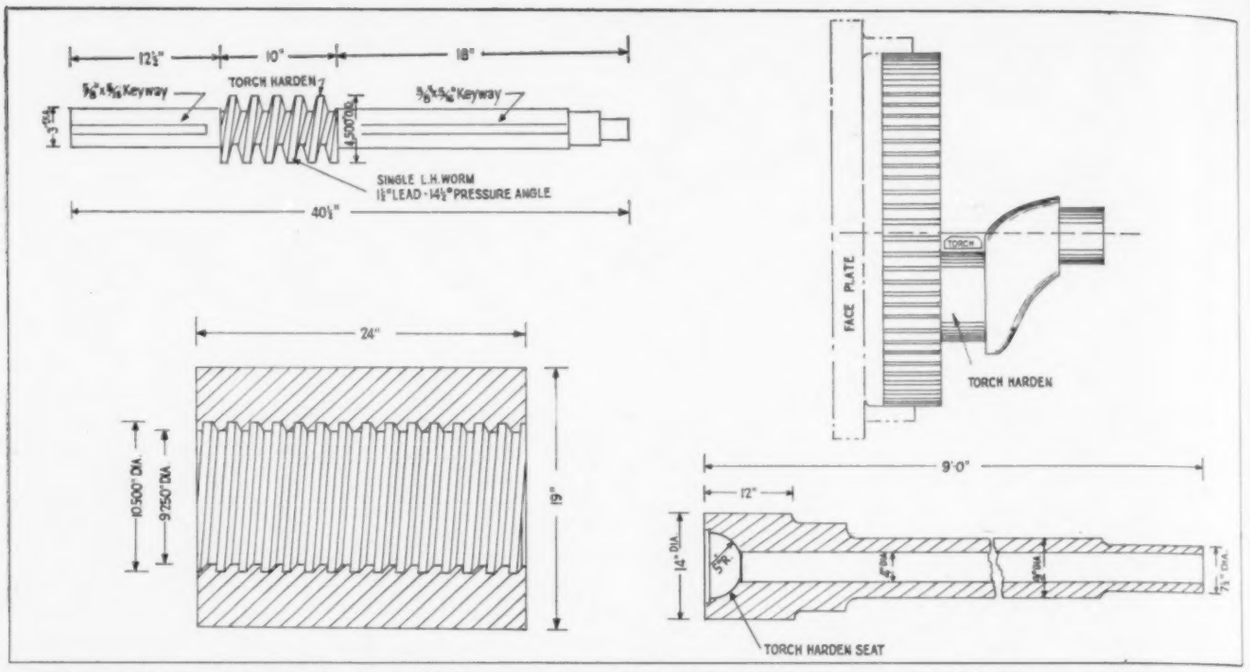


Fig. 5 (Bottom Left)—Internal Hardening Was Accomplished on This Nut. Fig. 6 (Top Left)—Hard Threads Are Required on This Worm. Fig. 7 (Bottom Right)—Distortion-Free Hardness Was a Requirement of the Ball Socket. Fig. 8 (Top Right)—Crankshaft Bearing on This Piece Required Greater Hardness Than the Remaining Sections

MAKES IDEAL APPLICATION

With a change in analysis this made an ideal application for the acetylene flame. The specification was modified to a lower carbon, S.A.E. 6130, to prevent checking, and the threads were hardened except for a distance of one inch from either end, to Rockwell 5862, without any distortion either in the worm threads or journals.

Engineers demanded that the ball socket on the spindle illustrated in Fig. 7 be hardened to Rockwell 50 minimum. They further specified that the parts be free of scale and distortion. To satisfy these requirements by conventional methods would have been impossible as it would have necessitated the quenching and drawing of the socket end prior to a machining operation with a resulting hardness under the specification.

If hardness was to be maintained, then the heat treating would have to follow the machining operation and this procedure would be accompanied by the usual amount of scale and distortion. Being fabricated from a carbon manganese steel of the analysis given below, this presented an ideal flame hardening problem:

Carbon	0.40–0.50
Manganese	1.60–1.90
Phosphorus	0.040 Maximum
Sulphur	0.050 Maximum

The spindle was mounted on rollers and the small end fastened in a chuck. A special head was designed to fit the curvature of the path and at the same time compensate for the difference in speed of rotation between the large and small diameters. By rotating the forging, and permitting the torch to remain stationary, it was possible to meet the engineering requirements.

The crank shown in Fig. 8 was cast with the gear integral, from "Meehanite" and for all intended purposes this material was more than satisfactory in the as-cast state, except that the crankshaft bearing was not sufficiently hard for maximum service.

If the assembly were treated to a hardness satisfactory for the bearing, the pieces could not be machined, and heat treating after machining made the cranks unsatisfactory for service because of distortion.

Supporting the cranks as illustrated and applying the torch to the bearing surface, the hardness of the desired portion was increased to Rockwell 58 C without distortion, leaving the rest of the assembly unchanged.

For years designers of heavy equipment have sought for a safe and economical method for hardening integral gears and shafts. The sections were usually large enough to give ample factor of safety without resorting to heat treatment but there always existed that problem of wear, which in the majority of instances was confined to the gear teeth, but frequently parts were scrapped as the result of scored journals as well as scored or worn teeth.

PRESENTS COMPLICATED PROBLEM

The gear shown in Fig. 9 was selected as an illustration, not for its size and weight, but chiefly to demonstrate the feasibility of torch hardening large heavy areas. The teeth were hardened in the usual manner, but the 8-inch path on the journals presented a more complicated problem. Using a $4\frac{1}{2}$-inch torch head, the torches were adjusted so that overlapping would leave a narrow oblique soft path about $\frac{1}{64}$-inch wide along the horizontal plane, and a soft spiral path of equal size around the periphery.

"Soft" in connection with the above is in reality a misnomer as these areas are not soft as the word implies, but they are softer than the abutting hardened areas and

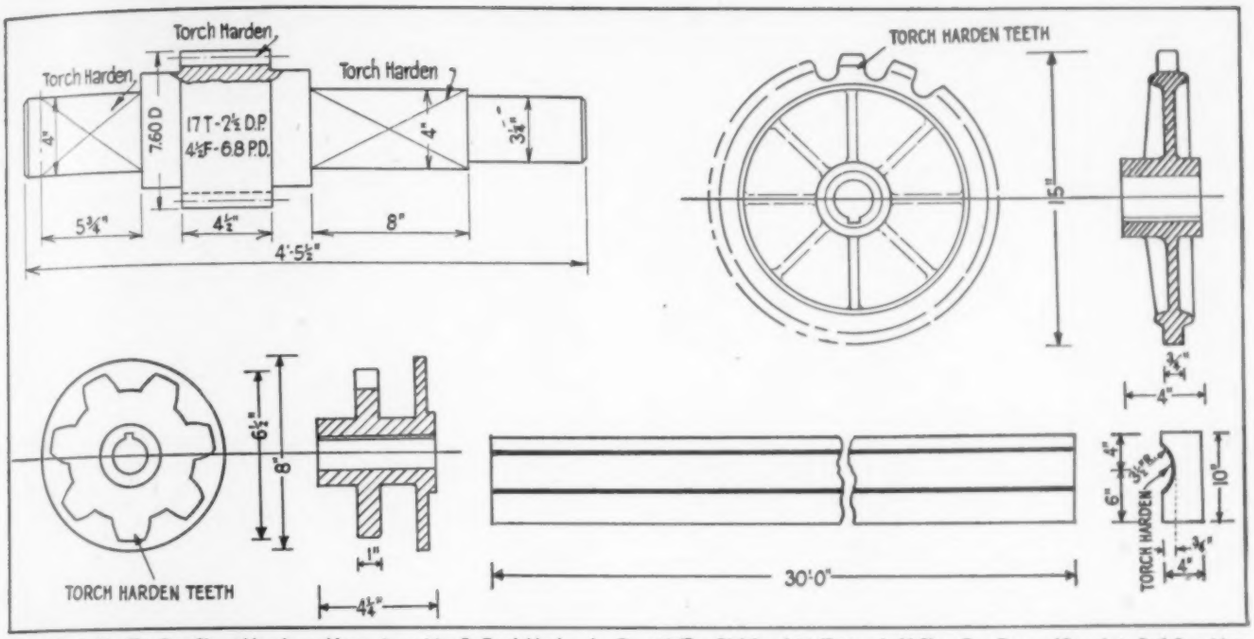


Fig. 9 (Top Left)—This Gear Shows How Large Heavy Areas May Be Torch Hardened. Figs. 10 (Top Right) and 11 (Bottom Left) Show Two Types of Sprockets, Both Requiring Maximum Tooth Hardness. Fig. 12 (Bottom Right)—One of the Longest Progressive Hardening Operations Yet Undertaken Was on the Raceways of Tracks 30 Feet Long

when checked with instruments they did not show over four points on Shore reading below the hardened sections.

Figs. 10 and 11 illustrate two types of sprockets which should afford no manufacturing complications. In both instances, the type of service demanded only maximum hardness of the teeth, allowing the remaining portion to be in the as-cast state.

The most logical solution to the design shown in Fig. 10 would be selective hardening of the rim only. With sound castings and proper equipment under careful supervision this procedure is very satisfactory, but handled in the average manner this method generally leads to disaster as invariably the spokes separate from the rim. Heat treating the entire casting is the practice most generally followed to eliminate the breakage, but this has several disadvantages, such as the teeth warping out of plane with the hub, increased machining costs and difficulty of holding maximum hardness because of machining requirements.

LONG RACEWAYS HARDENED

Probably the longest progressive operation so far undertaken was the hardening of raceways in tracks 9 inches x 4 inches x 30 feet, weighing approximately 3000 pounds each shown in Fig. 12.

These parts, machined from a 0.40–0.50 carbon steel, required the raceway hardened to a Rockwell of 52–55 C and at the same time no distortion was permissible. Hardening by the conventional process may have been possible providing an elaborate and expensive set of quenching jigs were used, but even then there would have been the possibility of sufficient distortion which would have required a long and expensive straightening operation or possibly the scrapping of one or more of the components.

Designing a special head to accommodate the radius, and mounting the torch on a monitor running parallel to the raceway, these tracks were hardened at the rate of 2 hours and 45 minutes each without scale or distortion and at a cost far under that of any other method of heat treatment.

ANNEAL FOLLOWING SERVICE

It is important, that where parts have been previously hardened, or have been in operation, that they be annealed before hardening. An excellent example of this was observed when attempting to flame harden forming dies.

The manufacturer in this instance was behind schedule and decided to run off several hundred pieces on the soft dies to satisfy his customer's immediate needs and then to remove the dies from the machine for hardening. This procedure is only logical and in all respects satisfactory, except in this instance he failed to inform the hardening room of the fact that the dies had been in operation. While flame hardening, the operator observed considerable checking of the hardened surface, which he attributed first to the flame and later to the analysis of the material. Considerable time was lost checking these factors only to find that they had no bearing on the trouble at hand.

On further investigation it was finally revealed that the parts had been in service. By turning off the quenching medium and slowly passing the torch over the area to be hardened, the parts were stress relieved to a sufficient degree so that no further complications arose during the hardening operations.

WELDING ECONOMICS and Application*

By E. W. P. SMITH†

THE prime purpose of the application of welding to the fabrication of any product is to reduce the cost thereof.

Cost, and therefore cost reduction involves really two items. The first of these is what we term the first cost and the second of these is the service life or the performance of the machine or equipment. If, for the same length or duration of time during which satisfactory performance exists, the first cost can be reduced, then there is a cost reduction. Or if satisfactory performance time can be increased for the same first cost, then there is also a cost reduction. In other words, cost reduction is measured in the service life and the cost for that service life, giving a cost for a unit of service life. If the cost of this unit of service is reduced then the entire cost of the product is reduced. It is, of course, very evident that the first item, that is the direct reduction of the first cost, is the one most usually demonstrated but performance must not be lost sight of.

The performance or service requirements involve the design and the design involves cost. The problem is studied from the viewpoint of cost, service life, design. It is necessary to consider in this service life the kind of load. Load conditions do not in general exist in what might be termed the pure state but in most cases exist in fairly intricate matter and in some cases an exceedingly complicated matter. Before proceeding to the consideration of the complicated problem, it is well to give some thought to the load conditions from the elementary viewpoint and then follow this up with a combination of the various elementary load conditions as they contribute to the service performance and cost reduction.

There is, of course, the pure load condition such as tension, compression, bending. These loads seldom exist in a single state, but are generally combined in some manner usually characteristic of the service to be performed. Tension, compression, bending, etc., are thought of as being the results of load conditions, but no mention is made nor are the rates of application of the load suggested merely by the mentioning of tension compression. There is, of course, the dead load, steady or continued loading, such as the weight of a beam which has been placed in position. Then there is the gradual application of load such as the addition to any piece of equipment of devices or attachments which do not have purely a load carrying function. This may be illustrated by the addition of the floor system to beams. This is very, very gradually applied. The rate of application of the load may be gradually increased until what is termed an "impact" or "shock" load, an exceedingly rapid application of the load is reached. It is almost self-evident that in the case of the very slowly applied or steady load the conditions are very much different than they are when the load is applied very rapidly. The ability of weld metal and welded joints to meet these conditions as given above is illustrated by the pure tensile specimens Figs. 1 and 2, the bending specimens Figs. 2 and 3 and by the impact specimens Fig. 5. It is to be noted that the impact specimen shows an exceedingly high value. The rate of application is one load condition which must be very thoroughly studied and considered in the application of design to any piece of equipment. There is also the frequency of the application of the load. The frequency of application must not be confused with the rate of application. Impact load is a very high rate of application, but may be applied very infrequently. There is the relatively slow and rather infrequent application of the load such as exists in the case of a stamping press or bending brake. Other type of loads are such that the load is applied a great many times, such as the load existing on a punch press, or reciprocating parts of all kinds. This frequency

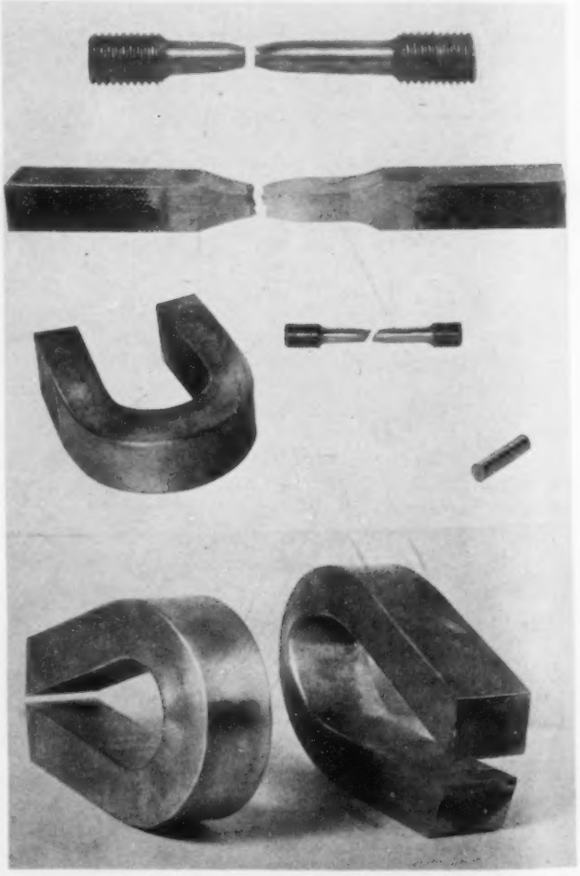


Fig. 1 (Top)—Tensile Specimen. Fig. 2 (Center)—Tensile and Bend Specimen. Fig. 3 (Bottom)—Bend Specimens

* Presented at the Convention and Iron & Steel Exposition, Hotel Stevens Chicago, Ill., October 1, 1937 (abstracted).

† Consulting Engineer, The Lincoln Electric Company.

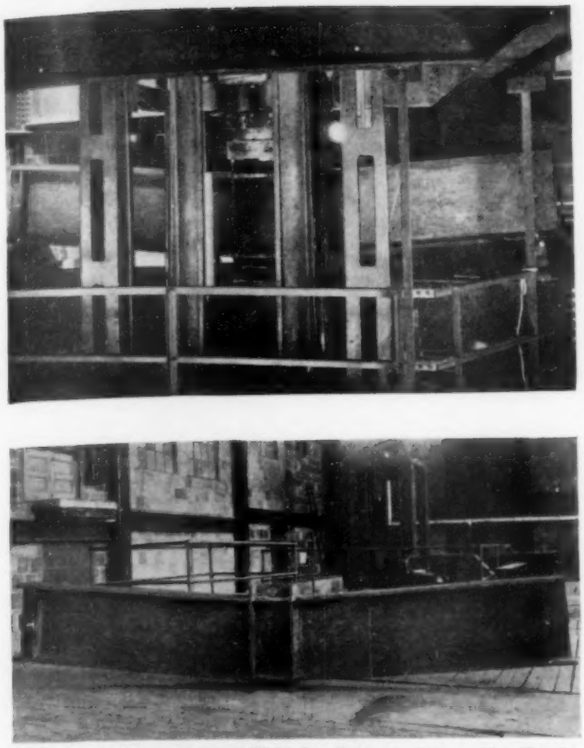


Fig. 4—Test Specimen with Beams Welded to Column in Center. Note That the Fracture or Failure Occurred in the Flange Coupling More Than a Foot to the Left of the Column

of application has a most decided bearing upon the characteristics of the design.

The variation of the load must also be taken into account, that is, from tension to compression or from a high tension to a lower tension, or from positive to negative bending or from positive to negative torsion. It has been found that when the load is very rapidly changed and the frequency is very high, or a great number of reversals occur, that the stress distribution becomes a factor which must be carefully studied. These are, therefore, a number of guides in the application of the type of construction used. The tension, the compression, the impact and the fatigue, the rapidly reversing load. The ability of the welded joint to withstand the load, is well illustrated by Fig. 6. This has been subjected to a stress of 32,000 pounds per square inch for ten million reversals and then has been bent upon itself 180 degrees.

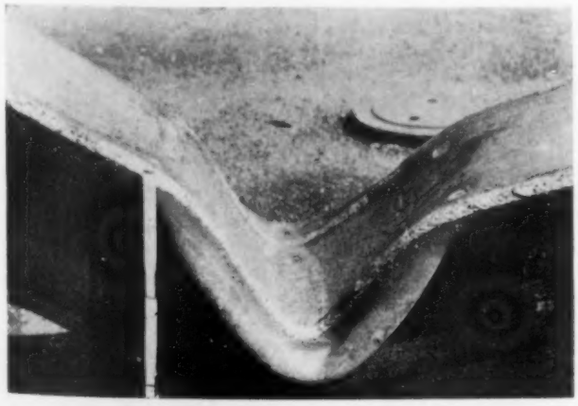


Fig. 5—Two Channels and Two Plates Subjected to Repeated Impact Blows Obtained by Dropping a Weight from Varying Heights. No Fracture in Weld or Base Metal

As mentioned above, all of these load conditions must be studied and the relation of the stress distribution in connection with this load must be given attention so that as uniform a stress as possible will be attained. It is obvious, of course, that if even the smallest section for a very small distance is stressed beyond the tension it will tear or break; that if even in the smallest section subjected to continued reversals, if the stress exceeds 32,000 pounds per square inch it will fail in a relatively short time. Welding fabrication permits uniformity of stress distribution and consequently the utilization of metal to the best possible advantage. This ability to perform and meet the service of load conditions of weld metal must, of course, be done at a low cost.

These costs are made up of several different items —power, the cost of electrode, the cost of labor, and the resultant quality of ability of the joint to meet load conditions. All of these must be taken into account when consideration is given to the item of total costs.

It is obvious, of course, that large generators are more highly efficient than the smaller generators and consequently the larger generator should be used. It is a characteristic of a welding motor generator set that the efficiency curve is relatively flat. In the case of a 300-ampere unit efficiency ranges from 47% at 110 amperes,

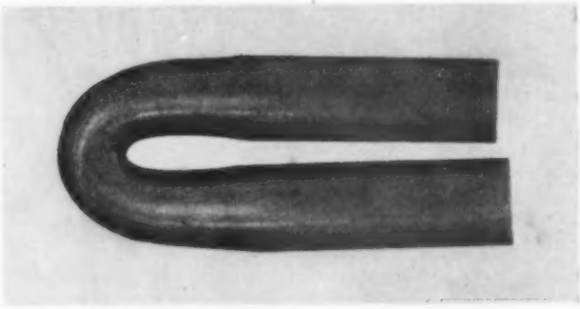


Fig. 6—Fatigue Specimen Subjected to a Stress of 32,000 Lb. per Sq. In. for 10 Million Reversals and Then Bent Upon Itself 180 Degrees

25 volts to 59% at 370 amperes, 38 volts, and even at the lower ranges the efficiency is not particularly less than that of smaller machines. Consequently this wide range and high efficiency of the large generator means a lower cost for power.

Table 1

Cost for Depositing 100 Lb. of Metal

	Electrode Size					
	1/8	5/32	3/16	1/4	5/16	3/8
Labor	$57.60	$45.40	$38.00	$20.00	$14.00	$9.20
Power	6.51	5.91	5.81	5.45	5.28	5.07
Electrode	15.75	14.75	12.75	12.75	12.75	12.75
Interruptions	5.40	3.60	2.40	1.50	0.90	0.60
O.H.	57.60	45.40	38.00	20.00	14.00	9.20
Total	142.86	115.06	96.96	59.70	46.93	36.82

Labor $0.75 per hour
Power 0.02 per kwh
50% operating factor
Overhead 100%

The Cost of Electrodes.—At the normal rated current it is discovered that it takes from 75 to 90 seconds to consume an electrode. It is evident, therefore, that if larger size electrodes are used that more metal may be deposited. Table 1 indicates this with reference to

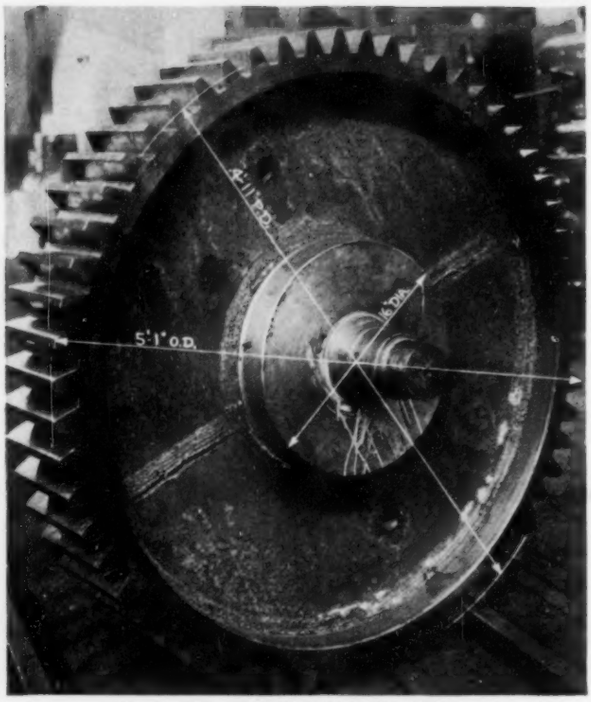


Fig. 7—Gear Completely Fabricated by Welding

a series of different sizes of electrode, indicating very clearly the higher rate of deposition for the large electrode and consequently the decidedly lower labor cost. Just the change from $^3/_{16}$-inch to $^1/_4$-inch electrode would involve a cost reduction of 25 to 35%. However, just because an electrode is consumed in a certain time is no reason to believe that it is the most satisfactory.

FABRICATION OF PARTS

In the fabrication of parts, is the matter of expansion and contraction, which should be considered. It is found that the use of a few number of beads has a tendency to reduce the distortion as compared to the amount of distortion obtained by using a greater number of smaller beads. This, of course, is an advantage obtained by the use of larger electrodes. Therefore, it would seem that in the matter of cost the use of the larger electrode at high speed produces a deposit at a lower cost per pound, and in addition to that the quality is of an exceedingly high order. It is high in ductility, with less distortion, and it is therefore advisable to use the largest size electrode which the design or fabricated part will permit. It is to be very carefully noted that this limitation or qualification is placed upon this statement and in addition to that it is also to be carefully noted that in general the tendency is toward the use of too small electrode, consequently high costs.

Not much has been said directly about the application to steel mill machinery, but a few illustrations will show the applications of this method to steel-mill machine (Figs. 7, 8 and 9). The terrific shock, impact and fatigue load, the high load encountered in steel-mill service make it necessary that the weld metal and the joints be able to meet the load conditions satisfactorily and at a low cost.

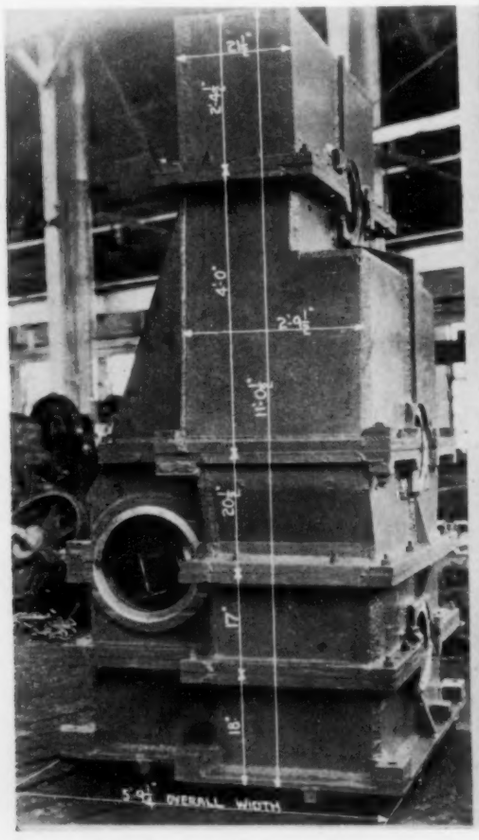


Fig. 8—Welded Steel Mill Housing

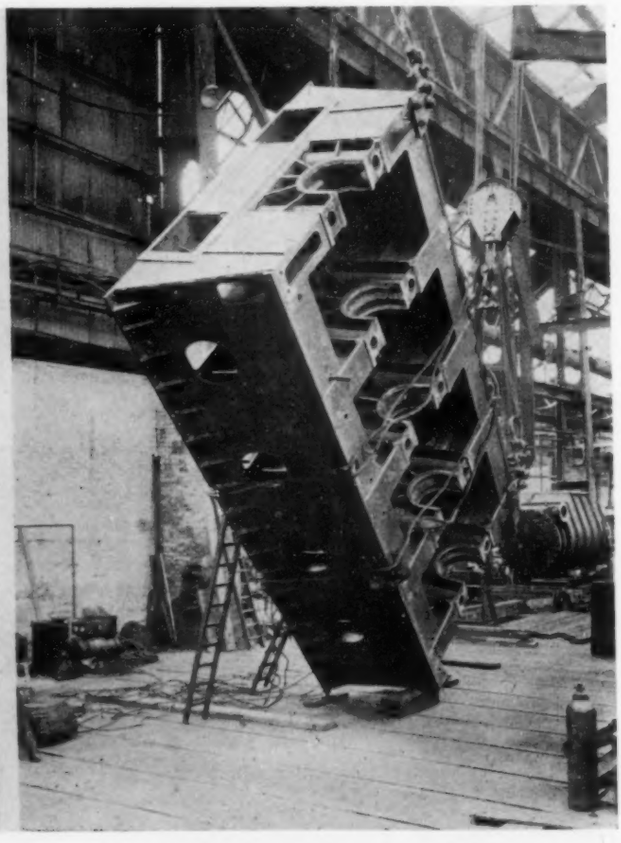


Fig. 9—Arc-Welded Diesel Engine Frame

A Discussion on the Effect of Welded Top Angles on Beam-Column Connections*

By H. W. LAWSON†

WHILE the sustained-load and repeated-load tests of the report by Inge Lyse and G. J. Gibson, October 1937, are encouraging, further tests will be necessary before the principles involved will be generally accepted. In order that the valuable data obtained by these investigations is not wasted, it is desirable that further tests be made to prove the validity of their claims.

What is contemplated here is the design of a structural assembly, one or more elements of which are stressed beyond the yield point when the structure is loaded with the design load. That a flowing or yielding of the elements takes place under the initial occurrence of the design load; which yielding ceases at some predetermined point, and no further yielding occurs for the life of the structure under any loading not in excess of the design load.

If this theory be correct it is justified economically and applicable to riveted structures as well as welded structures. No Building Code or specification anticipates the stressing of a load carrying member beyond its yield point while it is under load, even though it is now generally understood that a slow loading beyond the yield point increases the elastic limit and fatigue value of a welded assembly.

It therefore becomes necessary to produce such conclusive proof of the validity of the theory that code and specification writing bodies will accept the principles involved and permit their use in design.

Such a conclusive test would be a repeated-load test carried to a much larger number of cycles where the four- or five-hour flow period would be permitted to operate on each cycle of loading. The load should be the design load and the set-up preferably a beam between two columns.

The same effect as contemplated in this theory may be obtained by preloading the beam before welding the top angle, using a removable shim between the top angle and the column until the welding is completed. The loading should be that which would produce a deflection equal to the design-load deflection reduced by the elastic deflection of the angle under the same load. (Fig. 1.)

Such an assembly could be tested under the same conditions as those suggested for the repeated-load test of the contemplated design. Should favorable and similar results be obtained for both specimens it would constitute conclusive evidence that plastic yielding caused no permanent damage to the connection and the theory is justified, since the two assemblies are identical except for the plastic yielding of the top connection of the specimen of the proposed design method.

The connections described in this report would have much wider application were they applicable to spans of twenty feet or more, since beam-column connections of shorter spans are not very common. To apply these 3 x 3-inch angle connections to 20-foot spans, the permissible

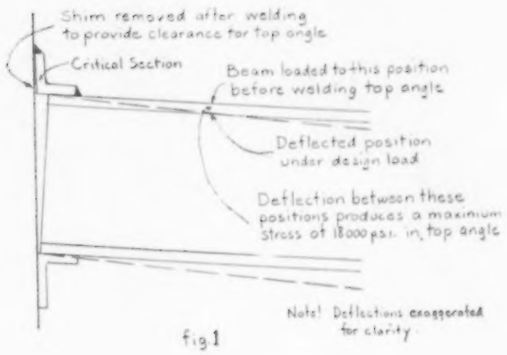

Shim removed after welding to provide clearance for top angle
Critical Section
Beam loaded to this position before welding top angle
Deflected position under design load
Deflection between these positions produces a maximum stress of 18000 psi. in top angle
Note! Deflections exaggerated for clarity

fig. 1

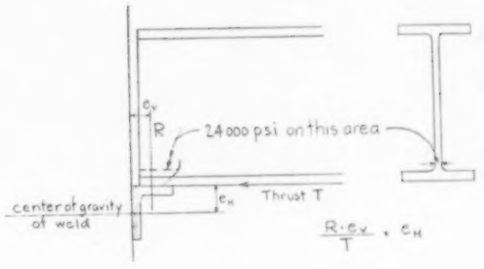


fig. 2

deflection would need to be increased from 0.070 to about 0.075. As the curves of Fig. 7‡ would indicate this would not be too great, but the question may be raised whether the authors would agree on this point.

In the design of the seat angle the moments produced by the horizontal thrust and the eccentricity of the reaction, have been neglected. While these values balance out in most cases, since one is a function of the other, it is desirable to check into this and proportion the length of vertical welds to aid in balancing these moments.

If it is assumed that the top angle carries some of the vertical load, the design becomes much more involved. It seems more desirable to design the top connection for pull only and the seat angle for the verticle load and the thrust along the bottom flange.

Assuming the reaction to be concentrated at the end of the beam, and the current A. I. S. C. formula for crippling of the beam web, the lever arm of the vertical load may be obtained. The lever arm of the horizontal load is equal to one half the length of the vertical weld. (Fig. 2.)

An excess of moment toward the column face at the top of the seat angle is not serious if the angle bears against the column web, but under any other condition the vertical weld should be designed for the resultant shear.

Conclusion 5 of the report states "The reaction of beams when welded to seat angles may be designed for the same loads as bearing on a stiffened seat." This statement separate from the report is not true. The weld ing of a beam to its seat cannot make the seat angle better able to support the beam except to the extent that free deflection of the seat is prevented. Within the limits of the theory, no appreciable error will result from this assumption, but wrong conclusions may result if the statement be taken too literally.

* Published in the Oct. 1937 WELDING JOURNAL.
† Engineer, Bethlehem Steel Co.

‡ Figure number refers to curves of paper by Lyse and Gibson, Oct. 1937 WELDING JOURNAL.

ARC WELDING IN THE CONSTRUCTION of Heavy Steel Presses for Automotive Industry

Shows Complete Practicability for the Heaviest Type of Design

By L. L. JACOBS†

EVERY day in the shops of the Clearing Machine Corporation of Clearing, Illinois, more and more convincing evidence of the adaptability of electric arc welding to the intricate, rugged designs of the heavy machine industry is being produced.

Here are built huge steel presses, ranging in capacities from three hundred tons to more than three thousand tons—and the range in weight is even more striking.

For this type of machine, where absolute adherence to close tolerances is of paramount importance, the use of alloy steel plates and arc-welded fabrication has come into its own.

When this organization entered into this field a few years ago, they developed their own all-welded designs, disregarded the thought of using castings as having many drawbacks, mainly from the angles of too much weight, the likelihood of imperfect castings, the delivery problem of having work done outside of their own plants.

As shown in the photograph below, (photo *A*) it is often necessary to have several men working on one unit. Six arcs are flashing on the below 400-ton, single-action 4-point suspension power press which is being built for use in one of England's largest automotive concerns.

The crown for this particular press with 132 inches die space between uprights weighs upwards of 45,000 lb.—entailed more than 450 man-hours of welding. Using approximately 1400 lb. of coated electrodes, these skilled welders averaged $^{3}/_{100}$ of a pound of rod metal for every pound of steel. Oftentimes, when the order is particularly rush, there are more than nine men welding on one unit.

† Buchen Co., advertising representative, Harnischfeger Corp.

Photograph *B* shows the block on which the upper die for the 400-ton press is attached. The weight of this unit is 24,000 lb., and it is made entirely from steel plate. Note the $1^{1}/_{2}$-inch steel chain used to handle it by the overhead cranes. The honeycomb sections of this and the above mentioned units are first tack-welded together by welders who do nothing more than this tack-welding operation—the unit is then taken over by the finishing welders who, as the photos reveal, are skilled in the art of laying a smooth, even bead.

HOW WELDED AREAS ARE PROTECTED FROM HEAVY STRAINS

Clearing Machine Corporation has developed their own method of making welds. This method, illustrated in Fig. *D*, shows how the steel members themselves are made to carry the principal strains of sheer or torsion and never the weld itself. The bearing hubs are thrust through the crown plate for support, then welded inside where the weld has a large section in compression.

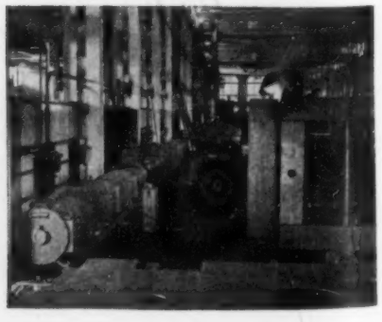
This method is much more expensive than other types, but is proved to be the most profitable in the long run, owing to complete lack of weld failures.

All presses constructed in this shop are built of steel plates in sections scientifically designed for welded construction. There is now a widespread and increasing preference on the part of press users everywhere for this type of construction. Their preferences are based on four principal considerations:

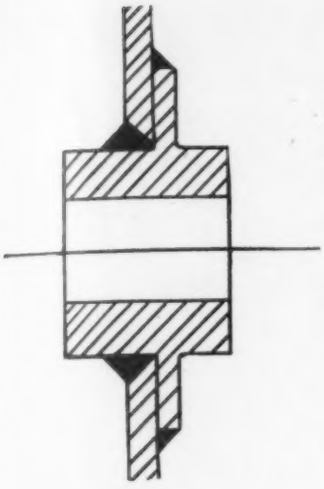
1. The exceedingly high modulus of elasticity of steel in comparison with that of cast iron that means almost a third less weight.

A

B



C

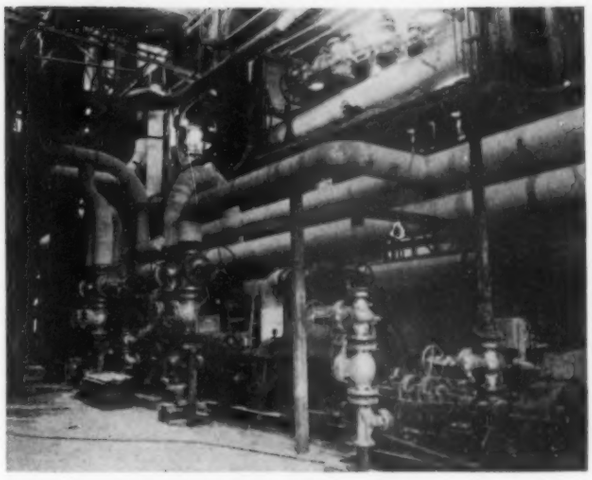


D

2. The high-tensile strength of steel in comparison with that of cast iron.

3. The homogeneous character of steel as against that of cast iron which is apt to have blow-holes and sand inclusions.

4. With welded steel construction, metal can be placed where needed, and members need not be unnecessarily bulky and clumsy to meet technical casting requirements.



Boiler Feed Pumps During Erection

Carnegie-Illinois Steel Corporation South Works—No. 5 Power Station

By A. C. WILBY†

A POWER project at the South Works of the Carnegie-Illinois Steel Corporation, identified as No. 5 Power Station, is scheduled for completion in the near future.

The project will consist mainly of the Power Station, the following equipment, and piping:

Three Steam Generating Units, each capable of producing 300,000 pounds of steam per hour at 475 pounds pressure and 750° total temperature.

One Condensing type Turbo Generator Unit capable of generating 25,000 kw. at 13,800 volts, 25 cycles.

Three Condensing type Turbo Blower Units, each capable of producing 75,000 cubic feet per minute of free air at 30 pounds maximum pressure for Blast Furnace use.

Two Evaporator Units capable of producing a total of 100,000 pounds of steam per hour at 160 pounds pressure, 50° superheat, for use in the adjacent mills.

Auxiliaries necessary for the operation of the Power Station, including boiler fans, preheaters, economizers, fuel supply system for utilizing blast furnace gas, natural gas and fuel oil, hot process water treatment equipment, combustion control equipment, surface condensers and equipment, pumps, etc.

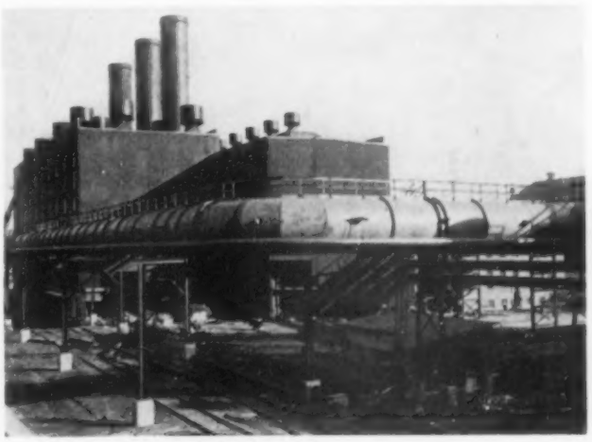
Connecting piping in the Power Station, as well as exterior piping between the Power Station and the Blast Furnace and mill systems. The exterior piping consists of a 10 foot diameter Blast Furnace Gas Main, 4 feet 0 inch and 4 feet 6 inch diameter Air Blast Mains, and 18-inch, 150-lb. Steam Main, a 12-inch Natural Gas Main, and a 3-inch Compressed Air Main.

The major items of Power Station piping, as well as the boiler drums, evaporator shells, condenser shells, surge tank, hot process settling tank and filters, deaerating heater, extraction heaters and fuel oil heaters are of welded construction.

The Station piping and pressure vessel welding was designed to comply with the A. S. M. E. code for unfired pressure vessels and in a majority of the cases is of the shielded manual metallic arc process, using coated welding rod. Welds for high pressure and temperature were stress-relief annealed. Flanges, which were used primarily at valves and connections to equipment, were of the welding neck type. Field welding was kept to a minimum by having all possible fabrication work completed in fabricating shops. This was done to facilitate erection and expedite the job. The majority of the welding was performed by qualified and Hartford approved certified welders. Chipping and peaning of welds was performed in accordance with good practice.

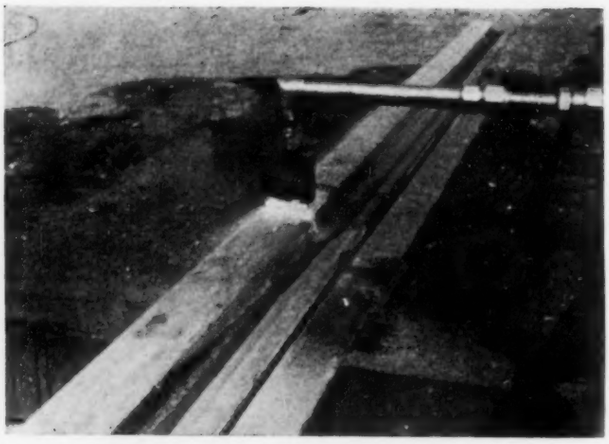
The 10 foot diameter Blast Furnace Gas Main and the 4-foot 0-inch and 4-foot 6-inch Air Blast Mains were installed by using welded type of construction. The shielded metallic arc process was also used in this case, but due to the low-pressure service, certified welding was not specified.

The 150-lb. steam main, natural gas main and compressed air main piping, connecting to exterior systems were installed by using welded type of construction similar to that employed for the Power Station piping.



No. 5 Power Station Showing Welded Exterior Piping

† Carnegie-Illinois Steel Corp.



Flame Hardening Has Solved Difficult Heat Treating Problems

Oxyacetylene Cutting Torches Are Playing an Important Part in the Present-Day Locomotive and Car Scrapping

REVIEW OF THE OXYACETYLENE Industry—1937*

By DR. GEORGE V. SLOTTMAN†

THE economic vigor of an industry is measured not only by the facility with which it suits its gait to the varying trends of the business cycle, but also by its ability to develop new processes as outlets for its products to replace that portion of its substance lost by the constant attrition of competitive industries. The year 1937 tested the vigor of the oxyacetylene industry not only to the limit of its productive capacity; it tested its ability to supply technical developments in large measure to answer the insistent pressure of the industries it serves to make things faster, cheaper and better. In reviewing the state of the oxyacetylene industry in 1937, special emphasis will be laid on these newer technical developments of our industry as they present themselves on the unfolding picture of the year's progress, and as they evidence solutions to the problems of industrial production.

SCRAPPING PROGRAMS

For industry in general, 1937 was a year of renovation, of expanding productive equipment, of scrapping obsolescent parts. The world armament race brought scrap from the steerage of freighter bottoms to the first class of luxury liners and this enhanced value of scrap added impetus to the desire of industry to make room for expansion by sloughing off outmoded equipment. Extensive and highly organized scrapping programs thus became a feature of the year's activity. In the heavy industries, where obsolescent equipment was plentiful and particularly in the railroads with thousands of worn-out cars to be replaced, the oxyacetylene cutting torch gave a ready answer to the problem of rapidly converting millions of tons of scrap to salable size. Thousands of new cutting torches were lit throughout the country and placed in the hands of men with no previous training in our industry. The problem of training these operators in particular and of taking up the slack caused by the general lack of oxyacetylene operator apprenticeship during the depression years, was thrust squarely upon our industry in intensified form by this scrapping activity. Operator training occupied a good portion of the year's service of our industry.

OXYGEN DISTRIBUTING SYSTEMS

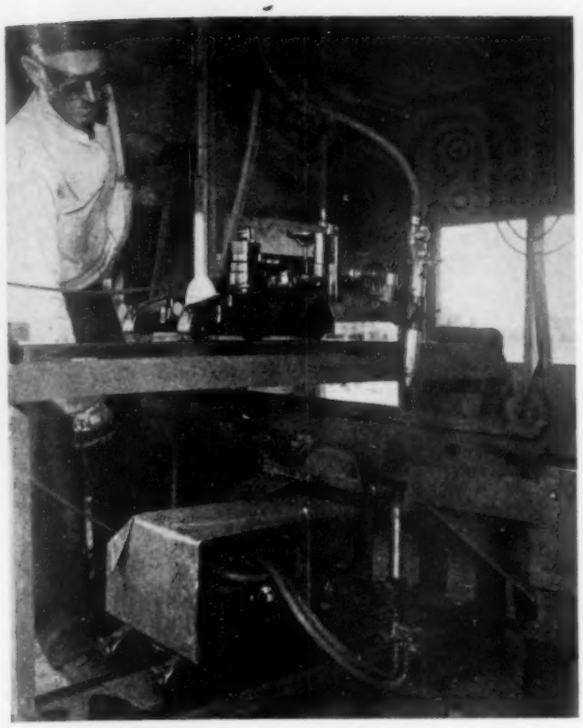
Another feature of the year 1937 was the increased acceptance of the oxyacetylene process as one which warranted a permanent investment in the form of pipe lines to distribute oxygen and in some cases acetylene from central locations to all consuming points. An ever increasing number of industrial plants have come to the realization that, with oxygen piped and conveniently available throughout a plant, many problems which yielded laboriously to the hacksaw or sledge, disappear entirely in the heat of the oxyacetylene flame. Oxygen, instead of being the proverbial plumber's tool to be gone after, stands ready to serve at the turn of a valve and tolerates no competitive process in speed or economy. The general availability of pipe line oxygen throughout industrial plants, and particularly in those departments where use is heavy, is coming to be the accepted form of oxygen distribution. The service of the oxyacetylene industry in fostering, planning and installing such piping systems has resulted in a wider use of its products, and has benefited industry in general by increasing the efficient and economic use of its processes.

STEEL MILL ACTIVITY

The use of oxygen to condition steel stock for the finishing mills, and to replace the chipping hammer, is becoming widely accepted. Formerly regarded as, at best, a salvaging process, to reclaim stock too badly cracked to warrant chipping, deseaming is taking its place as a pro-

*Read at the 38th Annual Convention, International Acetylene Association, Birmingham, Alabama, November 10th, 11th and 12th, 1937.

† General Chairman, Oxyacetylene Committee for 1937, Assistant Manager, Applied Engineering Department, Air Reduction Sales Company, New York.



Cropping the Battered Ends of Rails with the Oxyacetylene Torch Accounted for Considerable Savings to Railroads

duction tool of the steel industry. The advent of the high production continuous strip mills to be fed with large tonnages of conditioned slabs, and the increasing quality demands of steel consumers requiring finer conditioning of the stock, have brought the scarfing torch into the chipping yard. Larger sections, ingots, slabs and blooms are being generally skinned or spot scarfed with the oxyacetylene torch. The extension of the process to billet sections as small as 2-in. squares is in progress and promises to be as universally acceptable as the conditioning of larger stock. To quote the words of an executive of one of the country's largest steel producers, "The use of the oxyacetylene process for steel conditioning is without doubt the most significant development in the art of steel making within recent years."

MACHINE DESEAMING

Machine operation of scarfing torches marks a further development of the steel conditioning process. By mounting a number of scarfing torches on a traversing carriage, whole surfaces of blooms 14 in. in width can be removed at linear speeds greater than 2 ft. per sec. The problems of surface condition in high quality steels, which have been solved in the past by mechanical skinning tools, are now being attacked from the basis of using stationary scarfing machines permanently located at the blooming or slabbing mills to desurface completely the hot slab or bloom as it passes to the finishing mills. The operation of steel conditioning with the oxyacetylene process represents one of the finest examples of the service of the oxyacetylene industry to the basic industries of this country.

RAILROAD ACTIVITY

Railroad activity in car scrapping has already been commented on. As with the renovation of the rolling stock, improvement of the right-of-way was similarly studied. Wider application was made of the oxyacetylene process of rail joint hardening to resist batter, and the building up by welding of battered rail ends. A number of machines were developed with the purpose of making the rail end hardening process semi-automatic. Rail joint betterment programs running into hundreds of miles of track were common on the larger roads.

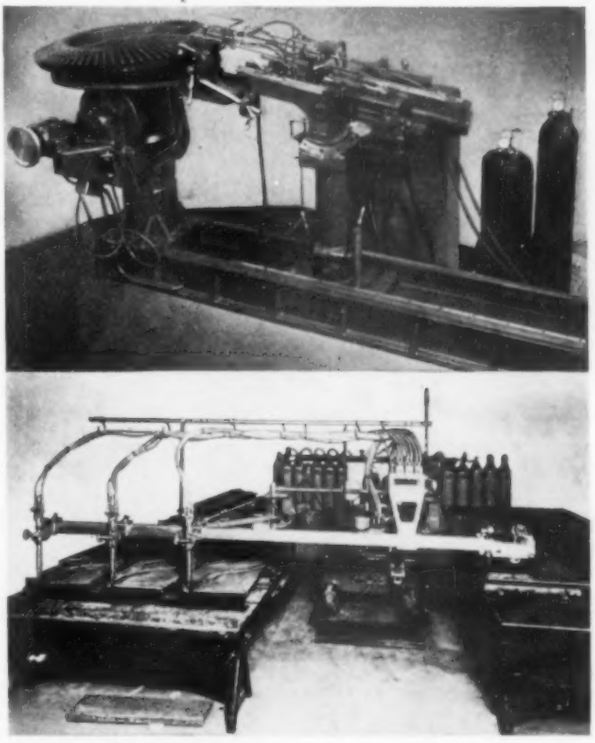
Several large rail cropping programs made use of oxyacetylene cutting machines in place of friction saws for producing a smoothly cut rail section, back of the battered end, suitable for re-service in the line and at a considerable saving in time and money over the older process. Rail joint welding to eliminate joint maintenance entirely and to improve electrical conductivity for signal and power circuits continued to find growing application. Oxyacetylene bronze or steel welding of mine car and industrial crane rails has become common practice. Several long tunnel sections of railroad rail were oxyacetylene steel welded. Experimental work on railroad track in the open has also been continued with promising results.

PIPE WELDING

The introduction of multilayer of multipass oxyacetylene welding of heavy wall pipe for high-pressure, high-temperature steam and oil lines marked a new development in the pipe welding field. The grain refining and stress relieving effects of multiple passes laid down with the oxyacetylene torch have allowed of obtaining physicals, particularly in ductility and impact resistance, suitable to the most exacting service.

Continued use is being made of multiflame tips and semi-automatic multiflame welding holders, particularly

Gear Hardening with the Torch with Multiflame Tips Has Found Increasing Applications



Marked Increase Has Been Noted in the Use of Machine Gas Cutting in a Wide Range of Industries

in the production double lengthening of pipe in the mill. The problem of welding casing in the oil fields of the southwest and of producing welds in the higher carbon ranges which will stand drastic quenching without serious effects on the physicals was investigated with promising results.

Mechanical welding of pipe and tubing using multiflame oxyacetylene welding tips was a very active field and the past year saw a large number of new applications of this process.

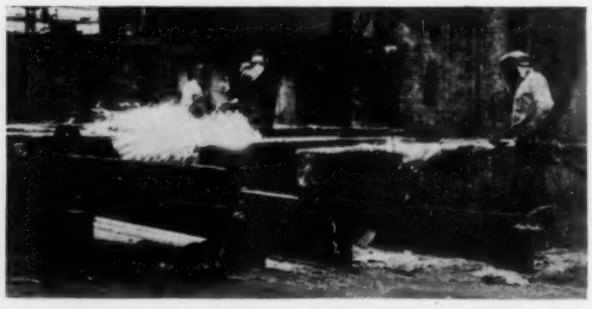
OPERATOR TRAINING

The wide spread acceptance and specification of welded piping in governmental resettlement and private housing projects during the past year created a demand for trained pipe welding operators which was successfully met by the cooperation of many educational bodies. Municipalities cooperated in offering the facilities of their trade schools. In some localities, trade unions offered courses to their members. Much of this educational work however fell upon the members of the oxyacetylene industry as suppliers of equipment of welding gases and our accomplishments in this phase represent one of the highlights of the year's activity.

NON-FERROUS ACTIVITY

In the non-ferrous field, the wide acceptance by codifying bodies of hard solders of the silver solder type, applicable only with the oxyacetylene flame, has opened up virgin territroy in replacing older methods of fabrication in general plumbing. Here again the problem of educating old crafts to new processes has fallen upon our industry. One of the most spectacular uses of silver solders, and one which will be discussed during the present convention, is in the assemblage of copper bus bars for collecting and distributing electric current in large central station and other power projects. Jointing of the bus bar members was formerly done with rivets. Vibration and the continual heating and cooling of the joints in service gradually increased the resistance of the joints, impairing its electrical efficiency and becoming a source of constant maintenance expense. Silver soldering these members provides joints of exceptionally low electrical resistance, high physical strength, freedom from maintenance and allows streamlining the bus bar assembly thus improving its utility and appearance.

Bronze-welding continues to be the accepted method of rebuilding worn parts and for heavy maintenance and repair work. As bronze-welding requires only tinning of the base metal to form a permanent bond, it is possible to repair many broken parts in place, using only light local preheating. Strong ductile welds are made, often superior in strength to the base metal. This makes possible the salvage of many expensive parts, and what is frequently more important, prevents long shut-downs of productive equipment. In this latter field, bronze-welding repeatedly performs in spectacular fashion to the benefit of the heavy industries.



Deseaming Ingots with the Oxyacetylene Cutting Torch Has Become Widely Accepted in the Steel Industry

FABRICATION AND MACHINE CUTTING

Increased use of fabricated parts and intensified activity in machine cutting development have marked the year's activity in the general manufacturing industries. A rapid transition in the status of oxyacetylene cutting from the roughing out tool to the accurately precise finishing tool is taking place. A wide variety of oxyacetylene cutting machines are available to the fabricating industries from the light portable straight line and circle cutting machines to production machines capable of cutting plates of unlimited length and in the greatest widths rolled, without movement of the work. Multiple torch operation on these machines allows of mass production of washers, flanges, car frames and similar parts.

Much attention has been given to the planning of fabricating problems, to the selection of suitable equipment from the variety of machines available, to the handling of material at the machines and to production scheduling to insure their efficient use. Portability and flexibility have always been considered among the prime advantages of cutting machines. This concept of a cutting machine, as being a portable tool to be brought to the work, has been changing in certain operations, particularly in riser cutting, to that of a tool permanently located on a production line working on the passing material.

The mechanical features of cutting machines are being constantly studied and improved to increase their precision and to reduce vibration, lost motion and other sources of cut irregularity.

DEVELOPMENT OF THE CUTTING PROCESS

The cutting process itself and the effects of oxyacetylene cutting on the physical properties of certain steels have been studied and the scope of the cutting field continuously expanded. Silicon structural steels have been more difficult to cut than mild steels without loss in impact resistance and in ductility of the cut edge, and such steels have sometimes required post-cutting machining of the cut edge to depths of $^1/_4$ to $^1/_2$ in. The use of multiflame heating tips either before or after the cutting jet to reduce the self-quenching action of the cold base material and to retard the speed of the air quench has made it possible to cut these steels without impairment of the physicals of the cut surface.

Similarly, with high-carbon steels which show a tendency to check at the cut surface, the use of auxiliary preheating flames to preheat the line of cut has made it possible to cut such steels without preheating the entire piece. Methods have also been developed for machine cutting the stainless and Monel clad steels, which have proved of great value to the industries using these materials.

FLAME HARDENING

An interesting development of the past year has been the revival and wide-spread application of the old process

of torch hardening. This process, variously known as flame, surface, selective or torch hardening utilizes the oxyacetylene flame as a heating medium in an operation metallurgically analogous to the widely used furnace hardening methods. Dating from the beginnings of the oxyacetylene industry and used in a limited manner in certain applications, the general utility of this process has been stangely restricted. Makers of heavy machine parts, too large or complicated to stand furnace treatment, have accepted the wearing-out of the contact surfaces of such parts as a natural concomitant to their use. That the contact surfaces of such parts, when made of hardenable material, could be hardened to depths of $^1/_4$ to $^1/_2$ in. without changing the physical properties of the core or without distorting the structure was not generally believed.

Starting with the contact surfaces of large gear teeth, this process has been gradually extended to cover a wide field of application including sheave wheels, cross head guides, cam shafts, ball races, sprocket wheels, shafts and other wearing parts common to machine design. The past year has seen an increasingly general recognition of the scope and utility of this process by machine manufacturers. An active development of suitable oxyacetylene equipment, particularly water cooled multiflame tips and torches, and machines for guiding these tips across the surfaces to be hardened, and a thorough study of the hardening technique are in progress, which will make the flame-hardening process steadily more serviceable to industry. The papers on flame hardening which will be presented at this meeting indicate the general interest which has been aroused by this process.

CODES

Continued acceptance of welding and cutting by the various codifying bodies has been a feature of the past year. Of most general import perhaps, is the allowance of structural welding in the recently revised building code of the City of New York, particularly since this code serves as a model for many other municipalities throughout the country. A broad increase in the use of the oxyacetylene process for cutting and preparing welding surfaces in the field is to be expected as a result of the more general application of welding in building construction. Similarly, the tentative Refrigeration Code of the City of New York has recognized the superiority of welded and brazed joints in refrigeration service.

New Method Eliminates Stresses in Welding High-Pressure Piping

By C. J. HOLSLAG†

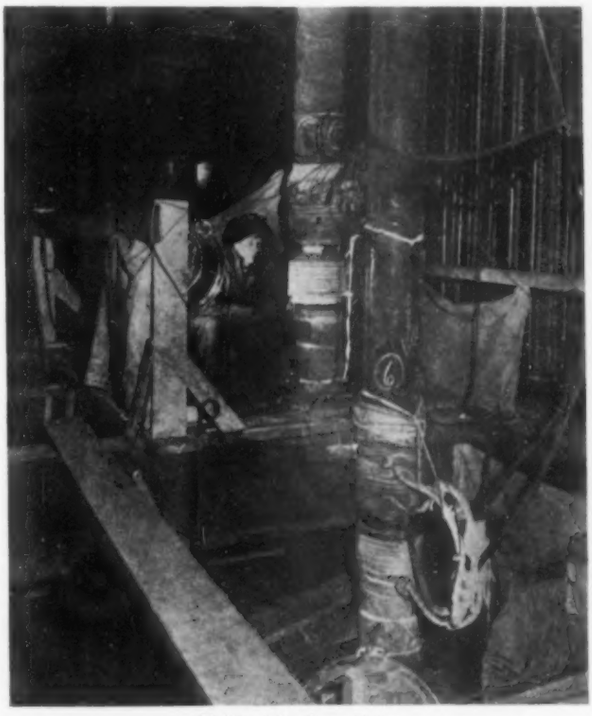
THE Public Service Electric & Gas Company has let a contract, which work is now in progress, to the United Engineers & Constructors for the improvement of their power generating facilities at their Essex Plant. A great deal of high pressure piping is embodied in this work and a new method of electric welding which includes preheating and normalizing the piping welds is being used.

While preheating for certain classes of work has been known for years to be a way of obtaining better and special physical properties of the weld, its application by this method is believed to be new. Arc welding has prided itself on its ability to weld mild steel without such previous heating but the introduction of alloys, especially the high-strength alloys used in modern power pressure piping, require for best results definite temperatures at which the weld should begin and end and further raising of the temperature to the desired normalizing or stress-relieving point.

This is being accomplished on the Public Service job with specially arranged coils of wire on either side of the weld, through which coils 60-cycle current is fed at predetermined amperages according to the size of pipe. The heat put in by these coils is at a lesser cost than by the electric arc and it is, of course, observed that the preheat reduces by that much the amount required from the arc source. The pipe is heated by hysteresis and eddy current losses; first to the preheating temperature and after the weld is made to the higher desired temperature by the same coil arrangement and held there as long as is required for best structure according to known heat treating developments. These temperatures are under pyrometer control and by means of taps and switching arrangement can be held at any level and for as long as desired. There is an inherent safety factor at the high temperature due to the loss of magnetism in the pipe or material being acted on. For lower temperatures a table has been worked out with voltage, accurately. In addition, visual and recording pyrometer readings are used together with a record of the current and voltage.

This system not only allows welding to proceed without change of location or connections to the heating coils but also allows caulking and peening and any other necessary mechanical work to be accomplished without hindrance. Reheating, if desired, is of course feasible.

† Electric Arc Cutting and Welding Co.



Welding Main Steam Piping

IMPORTANT USES OF THE OXYACETYLENE PROCESS in Steel Mill Operations*

By W. J. SANNEMANN†

INTRODUCTION

THE economic operation of steel mills is dependent to a great extent upon the element of time, and this, along with the production of quality products, is the determining factor in successful mill management. It is a well known fact that machinery fails due to wear and fatigue without giving any advance notice and when such condition arises it is vitally essential to have tools at hand that will expedite the repairs. In this the oxyacetylene process ranks at the top, due to its twofold use of removing the affected or damaged parts and then providing the medium through which the repair is made by the welding on of metal of suitable composition. This method of repair is not only adapted for speed of operation, but also permits work to be done without expensive removal to other locations.

The use of this process for cutting purposes in steel mill operation is of great importance due to its wide range of application and time-saving operations. In many instances it permits the removal of cobbles without materially disturbing the mill setup. These numerous applications will be taken up briefly by departments in order to show clearly their importance as pertaining to the successful operation of the present day steel mill.

BLAST FURNACE

Possibly one of the greatest time-saving uses occurs at the blast furnace in the removal of salamanders. Here the use of oxygen reduces the removal time to about one-fifth of that required by the old method. It may be of interest to outline briefly this procedure of removal in order to clearly understand the importance of this gas in maintenance work. Like all else, it becomes necessary at times to blow out the furnace for relining and in so doing there remains below the iron notch an agglomeration of metallic material which must be removed in order to rebuild the hearth area. The old method for doing this work consisted of drilling with churn or hand drills, a process that was slow and tedious with frequent sharpening of the drills. This, of course, was costly and great care had to be exercised in the selection of proper working materials. Then too, after the drilled hole was ready for shooting, tapered charges of dynamite had to be properly selected in order that the shot would not completely blow the drilled hole, a condition that would often arise due to the physical characteristics of this material. Small and carefully selected amounts of dynamite that would hold a charge of sufficient size to successfully break up this material for removal were first employed for the operation known as skinning out of a cavity within the salamander. If the charge happened to be too heavy the hole would be blown, that is, the constricted area at the top would be opened up in such a manner that any charge regardless of the size would not have the downward force sufficient to break the salamander.

The present method consists of burning holes by means of the oxygen lance. This can be done in a remarkably short space of time. The holes are burned to a depth sufficient to hold enough dynamite to break the salamander and the pressure of the gas is maintained sufficient to blow the molten metal of the salamander and the pipe out of the hole as the burning progresses. This factor necessitates a rigging that will permit a long line of burning-pipe to be used, as an interruption to tie on new pipe would permit a chilling of the hole, thereby presenting difficulties in starting again to say nothing of the economic questions involved. To overcome this feature, a string of pipes, sometimes as long as the height of the furnace stack itself are assembled and lowered by means of sheave from the top of the furnace. As the pipe burns, a control from the outside permits the operator to use the pipe at any desired rate of burning as one continuous operation. This facilitates a rapid method which is of economic importance in steel mill management and for which no other substitute has been found.

The number of holes, of course, is dependent upon the size of the salamander, as it must be broken up into sizes that can be removed through limited openings with mechanical devices whose lifting powers are also limited. The depth of the hole is variable according to some authorities, but many contend that a maximum depth of about 30 inches is the limit for economic cutting, as the molten metal has to be blown out by the pressure of the gas and the deeper holes would increase the gas cost and defeat the purpose of this process. Recently a salamander was removed from a furnace taken off for repairs, and to give some idea of the value of oxygen in this operation it may be well to point out that twenty-five holes were burnt in a period of twenty hours. The salamander, which is shaped somewhat like a saucer, measured approximately 5 ft. thick in the center, had a 26 ft. diameter and weighed about 275 tons. Only one shooting of the holes was necessary to break up this material in sizes convenient for removal from the furnace.

The skulling of ladles is another use for oxygen that is

* Read at the 38th Annual Convention, International Acetylene Association, Birmingham, Alabama, November 10th, 11th and 12th, 1937.

† Service Metallurgist, Tennessee Coal, Iron and Railroad Company, Birmingham, Ala.

worked advantageously around the blast furnace for speedy removal of iron skulls in transfer ladles. While these are some of the outstanding uses in this department, they are by no means the only ones; for in such uses as rivet cutting, pipe welding, removal of spills from slag pots, preparation of slag pots for welding and general construction, the oxyacetylene process has a most important rôle and must be considered a permanent tool in maintenance work.

FABRICATING AND WELDING DEPARTMENT

This department possibly uses the oxyacetylene process for more applications than any other branch of the steel mill both for cutting and welding. One application that is of interest is the oxyacetylene machine cutting of different shapes from heavy rolled plates. This in many instances offers a considerable saving due to the fact that certain vessels and structures can be cut and fabricated from rolled products instead of producing the same as a casting, which would have to be machined and in many instances be given a heat-treatment to remove casting strains. This feature can be readily appreciated when we see that the most intricate designs can be cut rapidly without the attendant danger of losing a casting as sometimes happens in foundry practice. Many other shapes are produced in the same manner that eliminate forging and machining operations, thereby reducing costs. The bronze-welding of broken castings salvages many pieces of machinery and turns them back into the line of operation in a minimum length of time. Lately the cutting and welding of steel pipe has become standard practice and this too, with its elimination of a threading operation permitting easier assembly, has materially lowered maintenance costs.

The building-up of worn parts with suitable abrasion-resisting welding rods has made rapid strides, particularly in the replacement of mill guides. A recent application of this on twist guides showed ten times the ordinary life of a chill guide and even then, this did not mean scrapping the guide as would have been the case of the chill guide; but merely the building up of more weld metal for further use. Other guides have been treated in a similar manner and in each case increased life was obtained with a lowering of operating costs. Many other uses for gas welding, such as assembling tuyères, monkeys and blocks for the blast furnace, fabricating of burners from pipe, and the preparation of tank plates by cutting are made in this department.

MILLS DEPARTMENT

In a great many instances, the value of the oxyacetylene process and its uses are identical in all of the mills. Therefore, in this paper, all mills have been grouped under the one heading. However, in some cases, certain uses are outstanding for economic reasons. For example, all mills experience cobbling at one time or another, particularly when changing sections, which calls for a complete realignment. In this instance the use of the oxyacetylene process as a cutting agent becomes invaluable in reducing delays by enabling quick removal of the cobbled section. This is often done without disturbing the mill set-up to any great extent and makes for an early resumption of rolling. If this handy tool was not available the time consumed in clearing the rolls would incur a great cost not only in delays, but possibly in damage to the material itself, which is at the proper temperature for the rolling operation. Again the process of rivet cutting and pipe welding are used advantageously in making repairs and other adjustments so necessary in mill operation.

In recent years the surface conditioning of looms, billets and slabs has become mandatory in the production of certain materials that must have a superior surface finish. This calls for the removal of any imperfections no matter how small, which sometimes means the complete skinning of the above mentioned sections. The oxyacetylene torch with certain tips has been used satisfactorily in this operation supplanting to a certain extent the orthodox method of conditioning, due to the fact that it has been proved much faster and decidedly more economical. The operator, however, must be an experienced one in this line of work as several conditions could arise that would make the worked section unfit for further rolling. Under this classification the scarfing test could probably be mentioned as it is of somewhat similar character, but the final results give an entirely different answer. The first is for surface conditioning, while the second one is for determining the internal soundness of the rolled section. This second test conducted in the billet yard is also rapid and replaces the expensive method of cutting, machining and etching the section to determine the soundness of the internal structure.

The cutting of plates too heavy to be sheared at the plate mill offers the opportunity for gas cutting these items at a low cost and supplying material which would otherwise be difficult to produce. Circles and semi-circles are readily produced, even in the thinner sections, thereby reducing the time and labor that would be encountered in shearing under straight-blade shears. These operations are carried out by means of a cutting machine.

OPEN-HEARTH DEPARTMENT

Here again the oxygen lance serves a useful purpose in the opening of tap holes in stationary open-hearth furnaces. This greatly speeds up the opening of the hole, in that the piercing with the lance permits the rod used as a punch from the front of the furnace to act also as a reamer, thereby producing a smooth, even, tapping stream. This, though it may seem odd, is considered by far a safer method of opening a tap hole. The old way of using a pricker bar, in some cases, caused painful burns to the helper whose duty it was to open the hole. It is hard to conceive how we would be able to work without the use of oxygen in this instance. In this phase of the operation the element of time is an essential item, so it is important when necessity demands that a furnace be taken off for repairs, that all possible speed be utilized in shortening this period of idleness. The cutting torch answers this need by quickly dismantling the members to be removed in making the repairs. Other uses, such as the welding and cutting of furnace doors in fabrication, the cutting of scrap to charging box size, removing iron and steel skulls from ladles and spouts, and the cutting of salamanders with the oxygen lance gives an idea of the wide range of application of this industrial tool.

LOCOMOTIVE REPAIR SHOPS

The bronze-welding of cast-iron locomotive cylinders by means of the oxyacetylene process shows a great saving in this branch of operation and many are reclaimed that otherwise would have been scrapped as unfit for further use. Also, the repair of coupling boxes and knuckles through this same medium has effected a

good saving. This is especially true of the knuckles which are subjected to rigid government inspection that specifies the clearance opening and which part received considerable wear. By building-up this part of the coupling assembly many are saved which would otherwise be scrapped. The welding of fire-boxes is successfully carried out, care being taken that the welded area is always below the water line. The building-up of various worn parts such as driving box liners for shoe and wedge faces offers further an opportunity for the utilization of this process. Grate bars repaired by welding have lowered the cost of maintenance in this department. Again the dismantling of cars for repairing and the scrapping of the same is effectively and quickly done by the oxyacetylene torch which otherwise would have to be done by the hand and tool method.

SHOPS DEPARTMENT

The pipe shop, machine shop, forge shop and electrical shop all realize the importance and value of having oxygen and acetylene available when certain conditions of repair and fabrication arise that demand an economical operation. To enumerate a few of the applications will give some idea of the scope of work done; pipe cutting and beveling with a special oxyacetylene machine; fabrication of fittings and headers; pipe welding; bronze-welding of motor cases and frames; building-up crane contact shoes, cutting mill guides, machine parts and gear blanks, removing risers from castings; and tipping machine tools.

There is also another use for oxygen that is practiced in many shops and which gives excellent results for this type of work. I am referring to the shrinking-on of bushings and the like by the use of liquid oxygen. On this operation, the liquid oxygen must be handled carefully to avoid any possibility of a mishap. The advantage of the use of this method over the old method of expansion by the use of heat is not hard to realize when it is considered that an excess of heat can probably cause a complete change in structure that would be detrimental to the material itself and probably be a contributory cause to early or immediate failure. The contraction, which in most cases calls for only a few thousandths of an inch, is rapidly obtained by immersion in liquid oxygen and upon attaining atmospheric temperature will cause a tight fit through the attendant expansion. At the present time there is an economical limit to the size of sections that can be successfully handled by this method.

CONCLUSION

These uses, which are only a few of the many employed, give some idea of the importance of the oxyacetylene process in the maintenance of the modern steel mill. There is no doubt that without it the cost of production of finished steel products would not be within the range of prices that exist today. The rapid completion of repair work on location make the oxyacetylene process an indispensable work tool in industry. The time-saving element along with the saving of expensive materials from the scrap heap proves beyond a doubt its economic importance.

Discussion of Paper Presented by Mr. V. Willoughby "Welding of Railroad Rolling Stock"*

By JULES MULLER†

MR. WILLOUGHBY has correctly interpreted the trend in car construction. His question "What of the Future" brings to my mind the early developments of fusion welding with heavy coated electrodes when the same question was in the mind of every one of us connected with the A. O. Smith Corporation of Milwaukee, the pioneer manufacturers of fusion welded vessel for high-pressure service in oil refineries.

In view of the similarity of conditions . . . let us benefit by the past experience and consider the answer to the then pressing question.

Mr. Smith instituted an expensive research program. He did not permit his product to be developed at the expense of the refineries. The product had to be right before leaving the plant. He realized that a failure would seriously retard the application of welding and, therefore, accepted the responsibility for the quality of the product during its normal service life. The records show that the future of welded pressure vessels was assured—through the self-imposed code of this company.

The future of welded railroad cars, and particularly freight cars, will be very bright for the manufacturer or builder who appreciates:

(*a*) The fundamentals of welding.
(*b*) That good fit-ups are necessary for good welding.
(*c*) That quality and speed are not synonymous.
(*d*) That the flaws in a weld cannot be always detected by visual examination.
(*e*) That the training of welders and supervisors of welding plays an important part in the success of welding.
(*f*) That proper and good equipment, as well as a good shop and conditions, are required to produce good welding.

We of our company have in the past years pioneered fusion welding on underframes. We believe in welding, but only in welding properly done. This year, through our inspection system, we supervised the fitting up and welding of more than 10,000 Cushioned Underframes. We found it necessary to closely supervise the welding—to insure and maintain the desired quality of the welds.

The future of welded freight cars will depend upon the quality of the welds and upon the design of the car. It is well to point out to the designer that a welded joint forms—and becomes part of—a continuous member. A welded joint is rigid, whereas a riveted joint slips when overstressed. These factors must *not* be overlooked—when considering the life of welded freight cars, especially when subjected to shocks inherent to switching or brought about by uncontrolled slack in train service.

* Paper presented before the Annual Meeting, AMERICAN WELDING SOCIETY, Atlantic City, N. J. Published in Oct. 1937 WELDING JOURNAL.
† O. C. Duryea Corp.

FLAME HARDENING*

By JOHN T. HOWAT†

DURING the World War the one important factor which was quickly recognized by our industrial leaders was the need for improved methods and new equipment and materials to meet the demands for mass production. As "necessity is the mother of invention," each succeeding year has seen more developments and inventions in all branches of our industries than at any other period in the past centuries.

The high standards which we have attained today in mass production of materials produced to physical, chemical and dimensional tolerances that were undreamed of years ago, would scarcely have been possible without the development of alloy steels and of methods for heat-treatment. These processes involved case-hardening, water, oil or air quenching, and each process imparted to the steel definite improved physical values accompanied by the natural distortion of the piece and residual quenching strains within it. For many parts this condition was unsatisfactory, with the result that the hardness would have to be drawn down to 250 to 300 Brinell so that they could be machined after treating, or else expensive grinding had to be done.

Eventually, in 1925, we were faced with the problem of developing a process that would enable us to heat-treat those parts which could not be handled by the regular processes due to their size, distortion or unsatisfactory wear or impact resistance obtained with 250 to 300 Brinell.

A research of the available metallurgical data revealed a process of flame hardening in use in England by the Metropolitan Vickers Company and the Patent Gear Hardening Company.

From a metallurgical viewpoint the process appeared distinctly radical and impractical, but after many weeks of development and research work we found the method to be very successful. The process depends on the skillful application of the oxyacetylene flame to the surface to be hardened, followed by the proper degree of quenching with water or air.

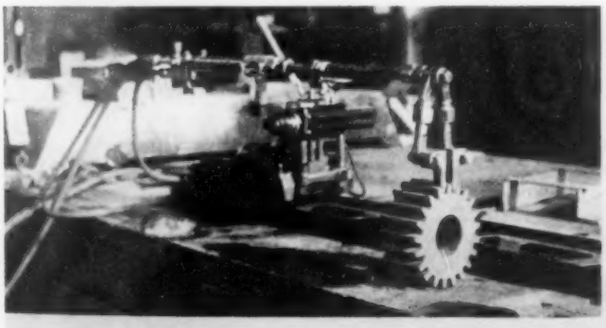
When you consider that we had established a method whereby we had successfully replaced our pyrometrically controlled furnace—having uniform light condition within the furnace and a proper quenching system, with an oxyacetylene torch and a water hose, to be used under varying light conditions under the control of a human being—it would seem distinctly radical.

Today, fully twelve years later, even though we now have several mechanical means of operating the torch and quenching equipment we are still dependent on the judgment of the operator to determine the amount of heat, the temperature to apply, and the extent of the quenching to obtain satisfactory results.

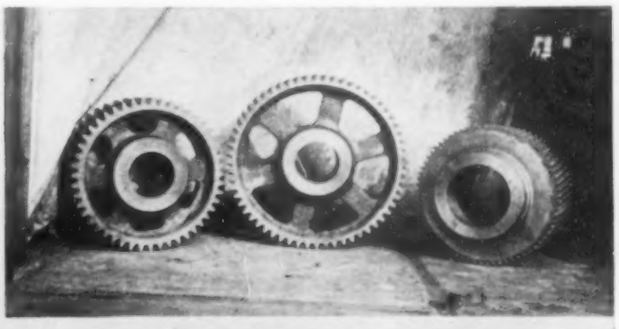
* Read at the 30th Annual Convention, International Acetylene Association, Birmingham, Alabama, November 10, 11 and 12, 1937.

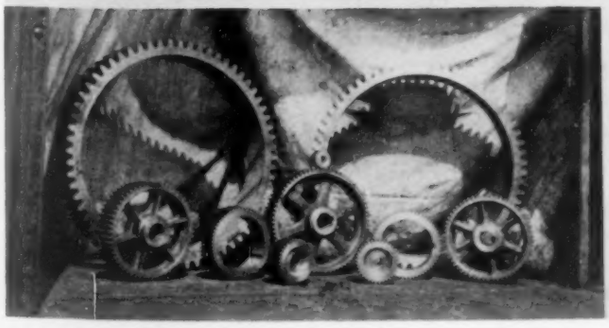
† Superintendent, Heat Treating Department, American Spiral Spring and Manufacturing Company, Pittsburgh, Pa.

A Machine Operated Water Cooled Torch Flame Hardening a 0.40 Carbon Steel Pinion of 10 Inch Diameter, 2 Diametral Pitch 6-Inch Face

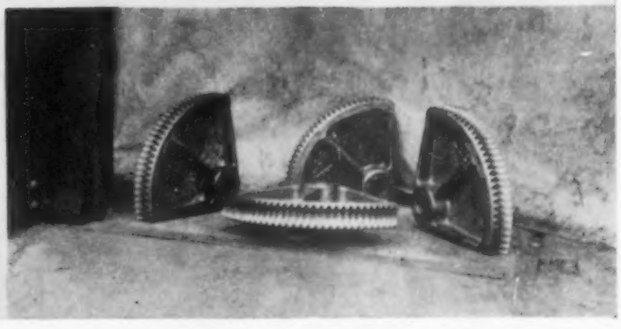


Two Large Size Industrial Gears of Slightly Different Design. (Right Hand) Forged Steel Mill Pinion 69 Helical Teeth, 2 3/4 Diametral Pitch, 10-Inch Face, Hardening Time 2 Hours. (Center) Cast Steel Industrial Gear 58 Teeth, 3 Diametral Pitch, 5 Inch Face, Carbon 35/45. Hardening Time 1 1/2 Hours

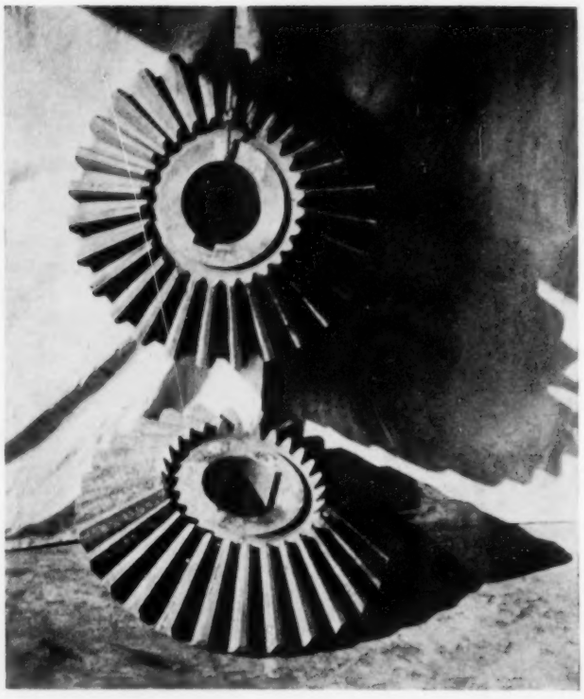




Flame Hardened Gears, Ranging in Diameter from 50.4 to 3 Inch Outside Diameter and 1 1/4 to 15 Diametral Pitch. This Group Will Illustrate the Variety of Sizes and Designs of Gears That the Commercial Flame Hardening Plant Handles Daily



Worm Gear Segments for Coke Ovens. Four Cast Steel Worm Segments Having 31 Teeth, 4 Diametral Pitch, 3-Inch Face, Used Under Very Abrasive Conditions on Coke Ovens. Flame Hardening Very Successfully Replaced Carburizing on These Parts



Blooming Mill Table Mitres Flame Hardened, 33 Teeth, 1 Diametral Pitch, 7-Inch Face. These Two Bevels Are Made of Cast Steel Carbon 45/50 Mang. 1.10 Chrome 1.00 Mo. 35. The Surface of the Teeth Are Treated to 650/750 Brinell

Naturally, with any new process or material, there is an unlimited field of possible applications and results to be developed so that after many months of experimental and service work, the following facts were definitely established.

The process is most flexible, and has an unlimited range of adaptability as size or shape of any part now offers no restrictions for heat-treatment, provided the surface area to be hardened is not too large a single area of thin section.

The process imparts to the steel the high surface hardness of the case or carburizing treatment with the toughness of a fully-quenched carbon steel, and the distortion and residual heat-treating stresses are all reduced to the minimum.

There is no sudden change in chemical analysis or microstructure with a sharp line of demarcation between the hardened zone and the core as is found in all case-hardened work. A hardened zone is produced at least two or three times the depth obtainable by carburizing, which will not spall with impact, vibration or deformation.

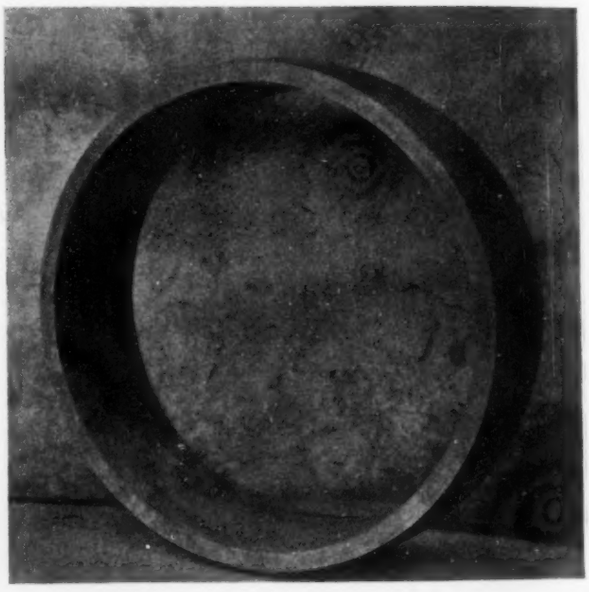
We have successfully replaced many applications where expensive alloy steels had been used to obtain the necessary wear resistance, by using the cheaper carbon steels, flame hardened. It is possible to harden carbon steels from 0.35 to 0.90 carbon to obtain a Brinell hardness of 400 to 700 respectively, but as the carbon or alloy content is increased greater care must be used in heating and quenching. Alloy steels that can be liquid-quenched or air-hardened can be successfully surface hardened. As the area being heated is only a small portion of the total mass, the quenching action is much faster than if the entire mass were heated and completely quenched. We are, therefore, able to obtain and use successfully in service, Brinell hardness values at least 30 to 50 points higher than those obtained by the full quenching method.

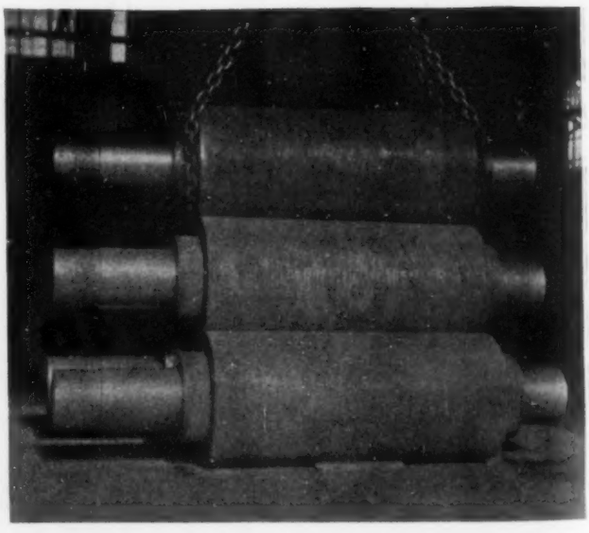
This is due to the balancing or tempering action of the metal adjacent to the hardened zone, which results in a fine tapering of the martensite with a gradual change to troostite and sorbite and finally pearlite in the core. The increased toughness resulting from this physical condition combined with the higher Brinell hardness accounts for the successful wear resistance obtained by this treatment.

As there is no hardening from $^1/_{16}$ to $^3/_8$ in. below the surface being treated, the balance of the metal will be in the soft annealed condition with minimum casting or forging strains. This accounts for there being practically no failures in service of surface hardened work, whereas fully 80 per cent of the failures of quenched work are breakages caused by residual quenching strains. Where possible a low drawing treatment of 400° F. may be used, but it is not absolutely necessary.

Many areas to be hardened require, because of their size, several passages of the torch across the surface, or the part may be rotated through the flame several

Grinding Wheel Mold. The Inside Surface of This Grinding Wheel Mold Was Flame Hardened. The Mold Is 26 Inch Outside Diameter with an 8-Inch Face. Hardening Time $2^1/_2$ Hours





Rolls with Hardened Necks for Direct Application of Roller Bearing. These Are Standard Table Rollers on Which a 5 Inch Width of Each Neck Was Flame Hardened to 350/450 Brinell to Eliminate the Necessity of an Inner Face for the Anti-Friction Bearing

0.35 Carbon Cast Steel Herringbone Tube Mill Pinions with Flame Hardened Teeth and Wobblers, 14 Teeth, 3/4 DP, 24-Inch Face to Harden 3 1/2 Hours, Weight Each Pinion 2500 Pounds

times. This means that there is an overlapping of the heat-treated areas, and where the areas join there is always a drop in hardness of approximately 10 to 15 points Brinell on a very narrow width.

Where flame hardening has to be applied to an unmachined surface, the surface should be chipped or sandblasted as free from scale as possible, as the scale will fuse on the surface under the oxyacetylene flame. Due to the decarburized surface of unmachined castings, the hardness after flame hardening, is usually about 30 to 40 points lower than with a machined surface of the same carbon content.

For this reason it is recommended to raise the carbon a few points for unmachined work. We have found that a cast steel of 0.35 to 0.45 per cent carbon and a forge steel of 0.45 to 0.55 per cent carbon will give very satisfactory hardness and service results.

Although we expect the distortion to be negligible or within machining tolerances, the part should be fully annealed to remove casting or forging strains where minimum distortion is desired. Should welding have been done, it should be followed by re-annealing if possible.

We do not expect this process to take care of all types of surface hardening as there are many applications where for various reasons it is not practical and some other method of hardening will have to be used.

The following tabulation of parts will help to convey some idea of the extent to which we have most successfully applied this process:

Industrial and mill gearing of all sizes from 3/4 DP to 16 DP racks and segments
Twist, barrel and plain mill guides
Coupling boxes, spindle and pod-ends
Bucket lips and tooth points
Thrust rings
Cams and cam-ways
Track wheels and rail ends
Paper pulverizers
Roll neck bearings
Roll tightening screws
Tube grips
Clutches, splines and key-ways
Abrasive wheel and other molds
Miscellaneous applications

In heat-treating the above parts only those surfaces required to resist wear or impact were hardened. To heat-treat the many varied surfaces above requires the use of a large selection of tips and equipment, ranging from a single tip to a multiple-flame tip.

It is almost impractical to attempt to give a figure for gas consumption per square inch of area hardened as this will depend on the style of tips used, the surface area being hardened, and the mass of metal under that surface. The area may be from 2 to 8 sq. in. per cu. ft. and 2 to 14 in. travel per min.

A careful flame hardening of the heat-treating semi-steels and cast irons will result in a decided raising of the Brinell hardness.

In conclusion, I should like to stress the following facts:

The process looks simple to the observer, but we must not forget that we are applying 6300° F. at a distance of 1/8 to 1/4 in. from the surface of the steel which we desire to heat to a temperature of approximately only 1450 to 1550° F. Application of the heat for a second or two, too close or too long, may result in burnt metal on the surface with brittle coarse grain underneath or overhardening and surface cracking. Uneven rate of application of the heat or quenching will result in hard and soft spots.

The selection of improper analysis steel may mean low hardness or cracking from excess hardness. Where alloy or high-carbon steels are used, the rate of heating must be carefully watched and the degree of quenching reduced considerably.

Irrespective of the type of equipment used, the operator should be a well-trained heat-treater capable of adapting his furnace experience to this new source of heating. He must be able to determine the proper time cycle of the heat period so that the correct depth of hardening will be obtained.

The careful application of the heat to sharp corners, etc., will eliminate most of the trouble experienced with surface cracking.

This paper has endeavored to present in a non-technical but practical manner, the procedure and results obtained in operating a commercial surface hardening plant.

1937
BOUND VOLUME

Bound Volumes of the JOURNAL of the Society for the year 1937 are now available with imitation black leather covers. Contains a wealth of information on the latest developments in welding. Also contains Subject and Authors' Index. Price, $5.00 plus postage to members; $6.50 to non-members.

JOINING COPPER BUS BARS with Brazing Alloys*

By R. A. GOELLER†

IN a recent operation at the Brooklyn Conduit Plant of Steel and Tubes Inc., a subsidiary of the Republic Steel Corporation, we were employed to install over 20 tons of copper bus bar on what is considered to be one of the largest electro-galvanizing plants in the country.

This installation was brought about by the necessity for expanding their present facilities, and the engineers of Steel and Tubes, Inc., wanted to provide a process that would turn out a superior and uniform product throughout the life of the plant.

A factor in this accomplishment was the installation of a bus bar system capable of delivering some 36,000 amperes at 4 to 5 volts. It was extremely important that the type of bus bar joints used should offer a minimum of resistance to the passage of this high current and also that maintenance should be reduced to the lowest possible minimum under severe operating conditions.

To convey heavy electrical currents to points of use in power plants, sub-stations, electric furnaces and other industrial applications, it is necessary to resort to larger cross sections of copper than are generally available in wire. Rectangular copper strips or bars, known as bus bars, are frequently employed for this service.

It has been common practice to join bus bars by mechanical means, using clamps or a bolted joint. To provide sufficient contact area between connecting bars, it has been customary to lap the bars for a distance at least equal to their width. The adjoining faces of the lap have to be carefully faced and thoroughly cleaned before the joint is made up. Unless the joints are carefully maintained, they may become oxidized. Copper oxidizes rather rapidly at room temperatures and this action is much more rapid when the joints in the bars are subjected to a daily heat cycle as often happens under operating conditions. The film of oxide formed offers appreciable resistance to the passage of electricity with the result that the voltage drop and heating increase at the joint. When these factors become excessive, the joints must be disconnected, recleaned and reassembled.

With the heavy operating currents of this installation, the joining of the bus bars was an all important problem. To avoid deterioration from oxidation and the resultant voltage drop, a combination soldered and bolted installation, using drilled holes, was specified. Due to the estimated cost of soldering the joints, some of which were made up of 8—6 inch x $\frac{1}{2}$ inch bars, the figures submitted on this basis ran considerably in excess of what had been anticipated.

Soft solder in addition to bolting or clamping has been used in the past in an attempt to insure a permanent joint and eliminate maintenance costs. Due to the cost of this method, its use has been very limited in commercial installations. Furthermore, it has been the practice to use the same size lap as for unsoldered clamped or bolted joints.

Alternate estimates were prepared based upon eliminating the soldering and a major part of the drilling. This idea was to use a 7-inch lap and a 5-bolt clamp, the 5th bolt to be centered between the other 4 and the copper drilled to receive it. In addition, it was planned to use a non-oxide grease or pure vaseline between the joint faces.

Other alternatives were considered, such as silver plating all joints before assembly and also the use of silver foil between each joint, but for obvious reasons they were dropped.

With the elimination of soldering, permanency of the joint depended upon two important factors, i.e., the proper surfacing of the contact faces to insure absolutely intimate contact with no interstices and adequate clamping pressure to avoid joint deterioration through oxidation.

While designing the bus bar clamps for this installation, having in mind the several problems, the idea struck us—Why not take a new departure in thought, sort of getting out of the rut, as it were. Every one in our organization agreed, but in what direction should such new paths lead? It was natural that electric welding should come to mind first, and pursuing the thought further, we found that portable equipment of several types was available, but not of the required capacity for this job. The cost of special equipment and the time required for its manufacture made us abandon the idea regretfully. The fact that one path had been closed, left us undaunted and now that we had broken away from convention in thought at least, we were not going to give up because of one set-back.

A telephone call was made to the Applied Engineering Department of a large manufacturer of gas welding sup-

* Read at the 38th Annual Convention, International Acetylene Association, Birmingham, Alabama, November 10th, 11th and 12th, 1937.

† Vice-President, Hatzel & Buehler, Inc., New York.

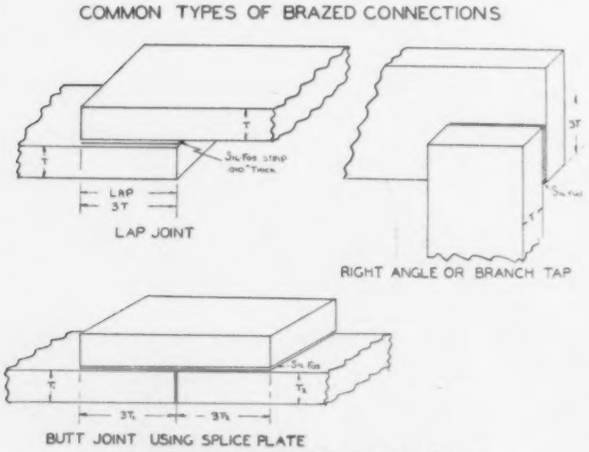


Fig. 1—Types of Joints Used on Bus Bar Installations

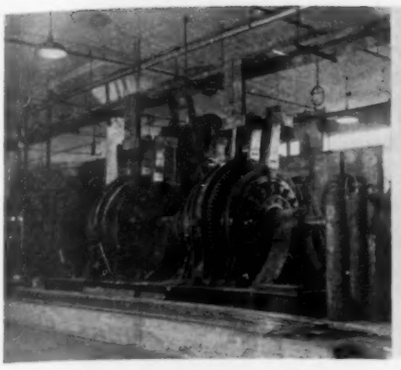


Fig. 2—View of Two of the Three 10,000 Ampere Generators. Connection to the Generators Are Bolted to Facilitate Removal Should Repairs to the Machines Be Necessary. The Bars Are Lying in the Hangers and Are About to Be Attached to the Vertical Feeders. Note the Three Cylinder Manifolds on the Oxygen and Acetylene Tanks. These Are Necessary Because of the Large Consumption of the Two-Flame Tip Used for the Heating Operation

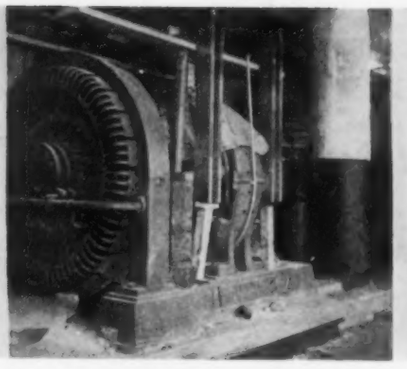


Fig. 3—This Is the Third Generator and Shows a Slightly Different Arrangement for Connection of the Generator to the Delivery Bars in the Hangers

Fig. 4—The Operator Is Brazing One of the Connecting Bars. Due to the Large Mass of Copper, It Is Impossible to Heat Them Collectively. Each Joint Is Made Separately Working Outward from the Inside

plies—an explanation of our problem—and this answer, "We are very much interested in it and confident that a perfect joint can be made by using a low-temperature brazing alloy. We would like to send over our engineer at once to discuss the whole situation, particularly the means of testing for electrical characteristics."

Over they came in short order. In the conversation that ensued, there were discussed the several brazing alloys available and their cost, the type of torches and regulators, capacities of gas tanks, methods of clamping, and last but not least, the skill required to make the joint and the labor time required.

In regard to the lap for the joint, it was decided that three times the thickness of the copper would be sufficient as far as mechanical strength was concerned. In the 6 inch x 1/2 inch bus bar which size represented the greatest bulk, this meant a 1 1/2 inch x 6 inch lap or 9 square inches of lap surface. How well this was justified both mechanically and electrically the following extracts from reports on test will show.

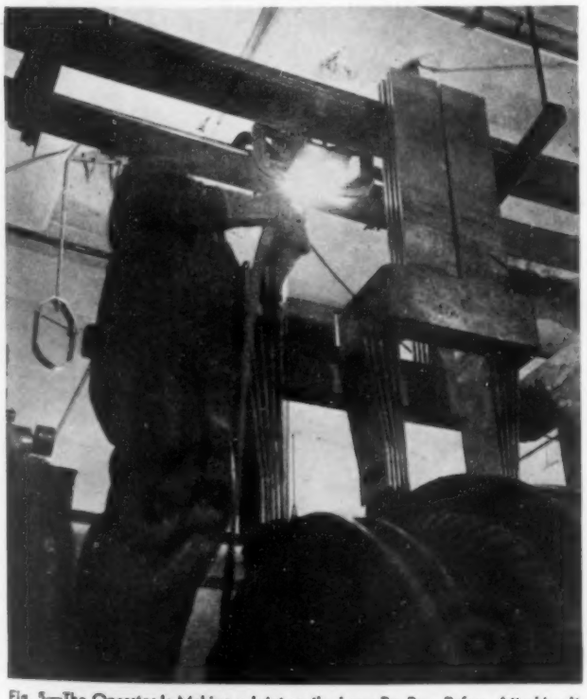


Fig. 5—The Operator Is Making a Joint on the Long Bar Run, Before Attaching It to the Generator Feeders

Necessary test pieces of copper were arranged for and several joints made in the laboratory of the Air Reduction Sales Co. with members of our staff present. Set forth below is their report on the cost of brazing alloys, gas and actual time expended in making the joints.

Cost of Brazing Test Bus Bar Sections

1/4 inch × 4 inch Bar—3/4 inch Lap—Sil Fos

Sil-Fos used 3/4 inch × 4 inch × 0.01 inch—0.15 oz. @ 3.50 per lb.	$0.033
Oxygen—No. 9 tip at 5 lb. sq. in, pressure 1.5 cu. ft. @ $1.60 100 cu. ft.	0.024
Acetylene—No. 9 tip at 5 lb. sq. in. pressure—1.5 cu. ft. @ $3.15 100 cu. ft.	0.047
Total material cost per joint	$0.104

$$\frac{\$0.104}{3} = \$0.035 \text{ per sq. in.}$$

Labor time—brazing 1 1/2 min. Cleaning, fluxing, assembling—3 min.

1/4 inch × 4 inch bar—3/4 inch Lap—Phos. Copper

Phos. Copper used 3/4 inch × 4 inch × 0.015 inch—0.2 oz. @ $3.80 per lb.	$0.047
Oxygen—No. 9 tip at 5 lb. sq. in. pressure—1.7 cu. ft. @ $1.60 100 cu. ft.	0.027
Acetylene—No. 9 tip at 5 lb. sq. in. pressure—1.7 cu. ft. @ $3.15 100 cu. ft.	0.054
Total material cost per joint	$0.128

$$\frac{\$0.128}{3} = \$0.043 \text{ per sq. in.}$$

Labor time—brazing 1 3/4 min. Cleaning, fluxing, assembling—3 min.

1/2 inch × 6 inch Bar—1 1/2 inch Lap—Sil Fos

Sil-Fos used 1 1/2 inch × 6 inch × 0.01 inch—0.45 oz. @ $3.50 per lb.	$0.099
Oxygen—Two flame No.10 tip—10 cu. ft. @ 1.60 100 cu. ft.	0.160
Acetylene—Two flame No. 10 tip—10 cu. ft. @ $3.15 100 cu. ft.	0.315
Total material cost per joint	$0.574

$$\frac{\$0.5734}{9} = \$0.064 \text{ per sq. in.}$$

Labor time—Brazing 3 min. Cleaning, fluxing, assembling—5 min.

NOTE: No allowance made above for depreciation wastage, lost time, etc. In comparing the material costs of these test prices, several interesting facts are evident.

The brazing alloy cost is directly proportional to the area of the lap, regardless of the thickness of bar used. The cost of gases rises very rapidly as the mass of metal is increased. Larger tip sizes are used to bring local area up to proper temperature as soon as possible to prevent heat being conducted through bar. The labor time is increased but this factor has no definite relation to mass since larger tips are used with larger masses of copper.

In passing it is interesting to note that during the tests, ordinary thumbscrews or *C* clamps were used to hold the lap together during the brazing process, and that similar clamps were employed in the fabrication of the job proper.

With the jointed samples completed and master test pieces without joints prepared, we were now ready to make both electrical and mechanical tests. Set forth below is the report of the Electrical Testing Laboratories on same.

☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆

TESTS OF WELDED BUS JOINTS

Introduction

This report gives the results of fall-of-potential and tensile-strength tests of brazed copper bus joints. The joints were made and submitted by the client. There were four joints tested, two joining $^1/_2$ inch × 6 inch copper busses and two $^1/_4$ inch × 4 inch busses. The joints were arbitrarily designated Nos. 1, 2, 4 and 5, respectively, by the Laboratories; the straight sections of bus were designated 3 and 6 for the large and small sizes, respectively.

Tests

The following tests were made:

1. Fall-of-potential measurements along 12-inch sections of bus both including and excluding joints.
2. Tensile-strength tests of one joint of each size.

Test Methods

For the purpose of comparing the resistance of each joint and a length of bus, all the joints and lengths of each size of bus were connected in series. The ends of the assembly were connected to a low-voltage heavy-current direct-current generator. The current was measured by calibrated ammeter and shunt. The current was adjusted to 1500 amperes by varying the generator field current. The fall-of-potential across a joint and along a section of bus was measured with a null-type potentiometer.

The tensile strength was determined in a standard tensile machine of 200,000 lb. capacity. The time from zero load to maximum was approximately five minutes.

Results of Tests

Fall-of-potential at 1500 amperes (D.C.) was as follows:

Test No.	No. Size of Bus	Length of Lap, Inch	Fall-of-Potential Between Two Center-Line Points, 12 Inches Apart, Mv.
1	$^1/_2$ inch × 6 inch	$1^1/_2$	4.0
2	$^1/_2$ inch × 6 inch	3	3.7
3	$^1/_2$ inch × 6 inch	(bus)	4.2
4	$^1/_4$ inch × 4 inch	$^3/_4$	13.0
5	$^1/_4$ inch × 4 inch	$^3/_4$	13.2
6	$^1/_4$ inch × 4 inch	(bus)	13.3

NOTE: The current was maintained at 1500 amperes for about one hour. The temperatures were not constant and no effort was made to prevent heat flow from one section to another. The temperature was slowly rising during the test period.

Tensile Strength

Tensile tests were made on joints No. 1 ($^1/_2$ inch x 6 inch x $1^1/_2$ inch lap) and No. 4 ($^1/_4$ inch x 4 inch x $^3/_4$ inch lap).

The breaking loads were 68,500 lb. and 24,900 lb., respectively. There was no definite indication of the yield points.

☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆

Three outstanding facts are obvious from this report; they are:

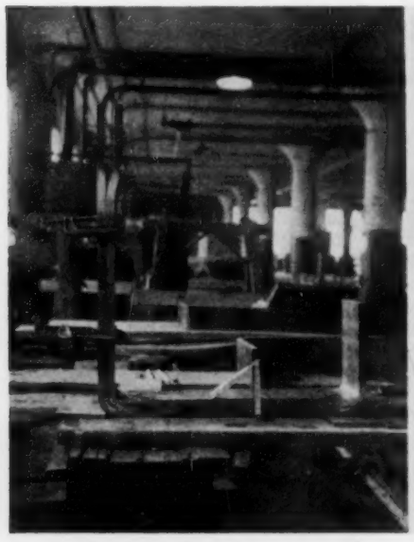


Fig. 6—Some of the Joints Were Made on the Work Bench. The Folding Rule on the Horizontal Leg Shows That These Were Two Six-Inch by One-Inch Bars. They Were Not Brazed for the Entire Length but Are Joined at the Ends and at the Right Angle Bend

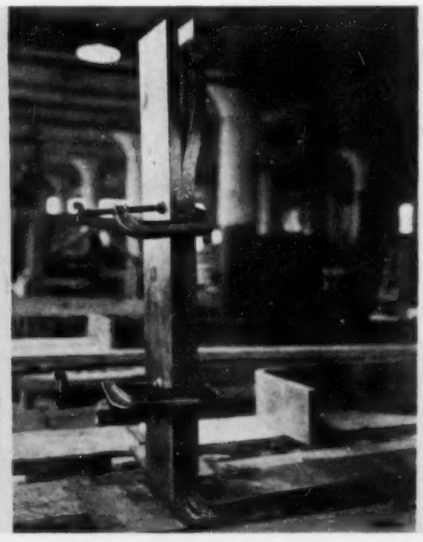


Fig. 7—This Is a Close-Up of the Joint Shown in the Previous Slide. In This Case the Bars Were Heated and Sil-Fos in Rod Form Was Fed in So That the Alloy Ran for a Depth of About Three Inches

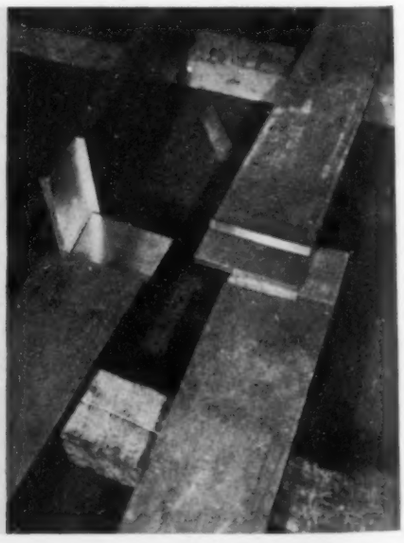


Fig. 8—The Joints in the Anode Bars Which Passed Through the Tank and Had to Be Insulated by Coating with Rubber Were Prepared in This Manner. These Bars Are 1 Inch x 6 Inches So They Were Notched for Three Inches by Milling

A. That the two pieces of 6 inch x 1/2 inch copper with a 1 1/2-inch lap joined by low-temperature brazing alloys had a lower fall-of-potential by 0.2 M.V. than a sample of similar length without a splice.

B. The tensile strength of the joint was extremely high, as indicated by the fact that the 2—6 inch x 1/2 inch pieces parted at 68,500 pounds.

C. A lap of 1 1/2 inch on the 6 inch x 1/2 inch bus bar was ample, both mechanically and electrically.

With the result of these tests before him, Mr. F. M. Darner, Chief Engineer of Steel and Tubes, Inc. rendered a decision to proceed with the brazing method. Due to the mass of metal in each joint, it was decided to use a two-flame tip and three cylinder oxygen and acetylene manifolds, so as to provide an adequate flame and uniform pressure for the longest possible time.

It was decided to use Sil-Fos since it could be obtained in 0.010 inch thickness and had a low-melting point of 1300° F. which meant low gas consumption. Sil-Fos is a low temperature brazing alloy consisting of 80% copper, 15% silver and 5% phosphorus. In the application of the heat to the joint, phosphorus, which is present for the purpose of lowering the melting point, and which has a boiling point of only 550° F., may be reduced slightly in its percentage with the result that a higher temperature will be required to melt the joint apart.

In New York City, operators using large capacity gas tanks are required to have a permit from the Fire Department, and with characteristic foresight a number of electricians have been trained by the Local Union and have obtained their permits for similar work, and a call brought an unusually competent man, who, after making a few sample joints, a matter of only an hour or so, started the actual work and from then on it was carried through to completion without hitch or complication. The method of making the joint was simple.

1. The adjoining faces of the lap are cleaned with emery-cloth or with a power-driven sander.
2. The bars were lapped three times their thickness.
3. The lap distance is then scribed on each piece.
4. The pieces thus prepared are now assembled, inserting a sheet of brazing alloy between them. This strip of alloy should be cut about 1/32 inch shorter than the joint dimensions and a thin coat of flux applied to both sides. The pressure applied during heating will insure the alloy flowing to all portions of the joint.
5. The assembly is then clamped with ordinary *C* clamps, screwed up as tightly as possible.
6. The joint is now heated by an oxyacetylene torch until the alloy runs out at the edges.

In special cases a brazing alloy was used in rod form, similar to solder, to fill voids that could not be handled otherwise.

One important point in making joints in heavy bus bars having a multiplicity of laminations should be stressed here; it is the fact that each pair of bars has to be joined separately and not all as a unit. This led to some fabrication problems which were serious only in respect to the cost and which offset to some extent economies gained in other directions.

At the plating tanks a number of situations arose where brazed joints provided a method that was free from acid corrosion and subsequent deterioration normally present in a clamped or bolted joint. Thus, there were no bolts or clamps to corrode or produce reaction of dissimilar metals under acid conditions to develop failures.

Space saving was another factor in favor of the brazed joint because there are no bolt heads or clamps to contend with, and on the tanks proper a serious problem was solved where the anode bus, consisting of 3—6 inch x 1/2 inch bars in parallel had to be carried along between the top edge of the tank and numerous metal supports at right angles thereto Within the tanks, too, it was necessary to splice some 6 inch x 1 inch cathode bars that after fabrication were rubber coated. Clamping or bolting would have been difficult indeed and Fig. 4 shows how this joint was made. When completed it was as one piece, rubberizing was simplified and protection from acid assured.

The accompanying diagrams as shown in Figs. 1 to 4 illustrate the several joints used by us on this operation

Fig. 9—The Assembly of These Anode Bars Showing the Strips of Sil-Fos in Place. Ordinary "C" Clamps Were Used on All Types of Joints

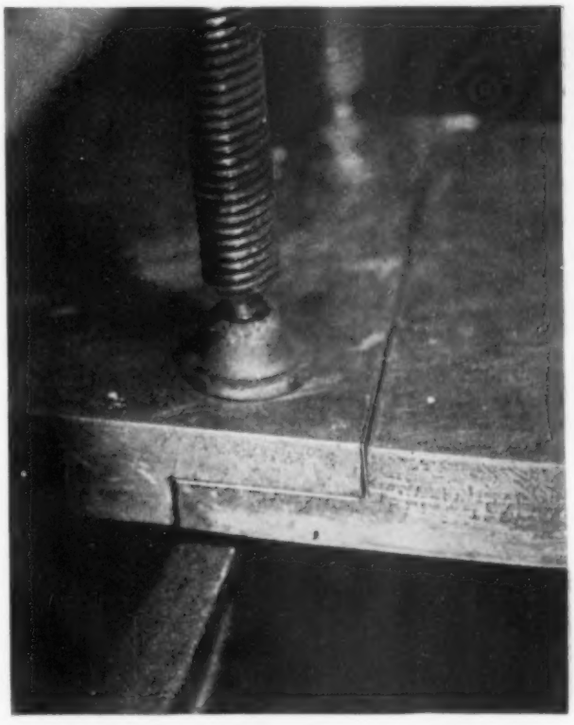


Fig. 10—The Heating Operation

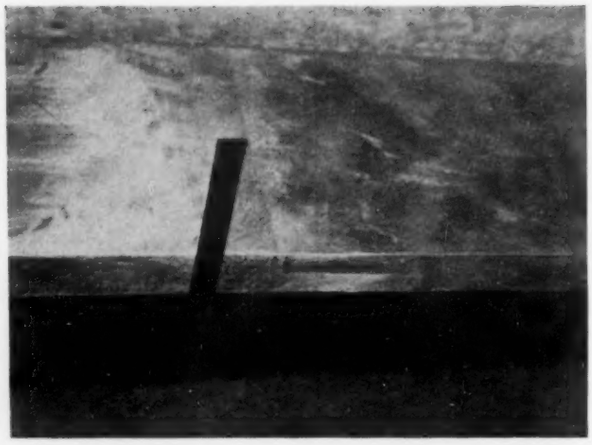


Fig. 11—The Completed Joint. The Surface Oxides Have Been Cleaned Off with Emery Cloth, Preparatory to the Rubber Coating Operation

and the formula which was applied for the various laps. Figure 5 shows another method using splice plates which was adapted on a subsequent operation and provided an arrangement where the busses were aligned at the joints rather than off-set. In long runs, and in exposed locations, this method is often desirable.

Figures 6 and 7 show the same principle as Fig. 5 applied to a right-angle joint and tap, respectively.

It is quite obvious too, that changes in direction or taps at more or less than 90° can be easily accomplished and a large amount of flexibility is provided in assembly through the ability to slide one bar over the other until properly positioned and then complete the joint. Joints in laminated busses with this method do not have the bulky appearance of the old method and in discussing the possibility of adopting this type of joint with an engineering representative of a large chemical concern wherein it was pointed out amongst other things that "the joint had a minus drop and greatly increased opportunities for radiation," he dryly turned and remarked, "So what you are trying to sell us is a bus bar system with aerated joints and if we put in enough joints we will be able to cut our voltage down to zero." We got the job and used the new type of joint, but it is doubtful if we will ever live down our high-pressure sales talk in trying to put the new method "across."

In making joints of this character, where heat is employed, expansion of the metal is a factor and, therefore, care must be taken in fabrication to allow for this and the subsequent contraction. The question has also been raised—why not a butt-weld? The answer is, it can be done but practical field difficulties do not warrant it, for it would be necessary to machine the ends, have special clamps to hold the bars in position and then put them under pressure. Expansion and the small margin of surface to work with, all indicate the lap method unless there are special conditions to be met with.

While the advantage of a joint impervious to corrosion, mechanically strong, having no greater resistance (less in fact) than a solid piece of copper and which will not change during the life of the joint are advantages of paramount importance, the question naturally arises, "What does this method cost over the old means of bolts or clamps."

The saving in copper poundage at the joints was unusual and based upon a 6-inch lap on the 6 inch x $^1/_2$ inch bars for the clamping or bolting method as against a $1^1/_2$-inch lap used for the brazing process and for the smaller sizes in proportion we have arrived at the following estimates of savings:

8—1 inch x 6 inch babbited joints	24 pounds
320—$^1/_2$ inch x 6 inch right angle joints	1410 pounds
6—$^1/_2$ inch x 5 inch right angle joints	6 pounds
40—$^1/_4$ inch x 6 inch right angle joints	102 pounds
96—$^1/_4$ inch x 5 inch right angle joints	72 pounds
192—$^1/_4$ inch x 4 inch right angle joints	103 pounds
Total savings in pounds	1717
Total savings in dollars ($0.18 base) 1717 × $0.18	$309.06

An analysis indicated that we had an approximate total 4233 square inches of brazed joint, and against this we had the following material costs:

Acetylene and Oxygen	$232.00
Sil-Fos and Flux	87.50
Welding torch and accessories—50% depreciation	149.23
Total material cost	$468.73

We, therefore, have the cost of material per square inch or joint as follows:

$468.73 divided by 4233 square inches = approximately $0.11

Or, specifically, joints for 6 inch x $^1/_2$ inch bus having a $1^1/_2$-inch lap, which were the greatest number, we had the following average costs of material for such joints:

9 square inches × $0.11 = $0.99

From the above data, for a joint in 6 inch x $^1/_2$ inch bus with $1^1/_2$-inch lap we have the following overall field costs:

Labor, welding and assembly (based on $1.70 per hr. plus 20% supervision)	$0.52
Oxygen, Sil-Fos, Flux	.99
Misc. expenses	.03
Copper ($0.18 base) bars—lapping $1^1/_2$ inch	.26
Total field cost	$1.80
Cost of Bolted Joint on Same Size Bar but with 6-Inch Lap (using drilled holes)	
Labor rate as above—drilling 10—$^1/_2$-inch holes with power driven press (5 in each 6 inch x $^1/_2$ inch bar	$2.00
Labor for assembly	1.05
5—$^1/_2$ inch x $1^1/_2$ inch steel bolts, nuts and washers	.40
Copper ($0.18 base) lapping 6 inches	1.03
Miscellaneous expense	.05
Total field cost	$4.53
Cost of similar joint when brazed	1.80
Saving by brazing method	$2.73
Cost of Bolted Joint on Same Size Bar with 6-Inch Lap but Using Punched Holes	
Punching holes (10)	$1.20
Labor—extra filing	.30
Labor for assembly	1.05
5—$^1/_2$ inch x $1^1/_2$ inch steel bolts, nuts, and washers	.40
Copper ($0.18 base) lapping 6 inches	1.03
Miscellaneous expense	.05
Total field cost	$4.03
Cost of similar joint when brazed	1.80
Saving by brazing method	$2.23
Cost of Clamped Joint When Using One Pair of 6 Inch x 6 Inch Cast-Iron Clamps	
Labor for assembly	$0.75
1 pr. cast-iron bus clamps	4.85
Copper ($0.18 base) lapping 6 inches	1.03
Miscellaneous expense	.05
Total field cost	$6.68
Cost of similar joint when brazed	1.80
Saving by brazing method	$4.88

The Summary of the costs of the various types of joints is as follows:

Brazed joint	$1.80
Bolted joint with drilled holes	4.53
Bolted joint with punched holes	4.03
Clamped joint (cast-iron clamps)	6.68

The labor cost per hour is the same in each case, $1.70 per hour plus 20% which includes Field Supervision such as foreman's time and other non-productive items but does not bear any burden for overhead or allowance for insurance, taxes, etc.

It also will be observed that the field cost of material per square inch of joint on 1/2 inch x 6 inch bus was 71% more in the field than in the laboratory, i.e., $0.064–$0.11 per square inch and is accounted for largely by the greater consumption of gas under actual working conditions.

On our second bus bar installation to which reference is made earlier in this paper, a slightly different type of brazed joint was used. In this case, the bars were butted and a splice or fish plate was brazed on one side. The plates were cut from the short ends of the regular bars and were made somewhat longer than was necessary to provide a three times the thickness lap on each bar. There was no necessity for this increased length from our point of view. However, it did provide more space on which to attach the four *C* clamps.

This job was not as extensive as the first inasmuch as there were only 10 tons of bus bars assembled. It was an excellent opportunity to test some of our theories regarding this type of fabrication. There was an entirely different crew of workmen on this job, and we felt that if everything went smoothly here, it could be honestly reported that no special workmanship is required for this actual brazing operation.

When we were ready to joint the bars, the gas manufacturer sent one of their servicemen to instruct our man how to handle a welding torch. More time was spent on the proper method of setting up the regulators, hose, and torch than on the actual brazing operation. A sample joint of two 3-ft. pieces was made up by our man with the serviceman offering suggestions from time to time. When completed, the joint was cut apart with a hacksaw in several places. The fusion of the Sil-Fos strip was complete and the workman was quite pleased because he had been able to do a satisfactory job with little assistance. The superintendent felt that it was not necessary to make up any more samples, and on the next day production work was started and carried on to completion in several weeks without any trouble.

While the joining involved in these installations primarily had to do with bus bars carrying heavy currents at low voltage, it also has a broad field of application where the systems operate on a higher voltage range at lower currents and has a large field of use in power plants and substations. In the first installation, for instance, this type of joining was applied very successfully in the primary and secondary bus bars installed in the substations constructed to supply power for this project.

It seems inevitable that jointing of bus bars by the use of low-temperature brazing alloys will grow rapidly when its possibilities are more generally understood. Its application to electrical uses is just one more indication showing the interdependence of industry and how the results of research conducted by such men as Mr. R. H. Leach of Handy and Harman Co., in basic problems, may open up new fields of application in specific industries thus making available methods having broad commercial possibilities.

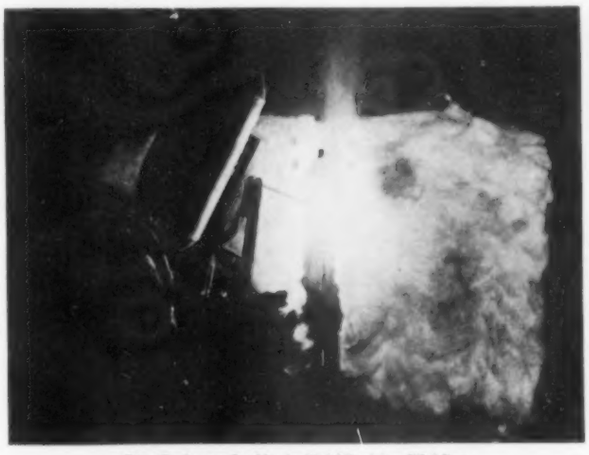
The circumstances surrounding the adoption of low temperature brazing alloys in the electrical field on a large commercial scale proves that the biblical adage is as fresh today as when quoted, "Seek and ye shall find."

Preheating Pipe

By C. M. WEINHEIMER†

DEVELOPMENT of a rapid and flexible electric preheater for use on alloy pipes before welding permits greater speed of installation, simplicity of operation, low maintenance cost and accurate temperature measurement. It can be used to preheat pipes before welding and during the welding operation without manual adjustment of the heating elements. Any temperature up to 600° F. can be maintained during the welding operation.

A special advantage is the protection afforded the welder during the weld and while the preheater is still operating. This is accomplished by the use of two insulating blankets which insulate the heating apparatus from the welder without inconveniencing him at his work.



Pipe Preheater for Use in Field Position Welding

The equipment consists of an indicating pyrometer, two-heat switch and an arrangement of adjustable heating elements in a connecting linkage which holds the heating elements in direct contact with the pipe. As a result a temperature of 600° F. is reached in less than three-quarters of an hour on a six-inch carbon-moly. pipe. Similar heating-up rates are possible on larger pipe sizes. The equipment is designed for operation on any 220-volt power line, single phase. Heaters are arranged for heating a distance of approximately four inches on either side of the weld to a temperature determined by the operator.

The apparatus is flameless, and being of low mass, it is rapid in its action. It requires less than 30 kw. for operation and is designed in two sizes, one for pipe sizes up to a maximum of 14-inch pipe, and a second to handle up to 24-inch pipe.

† Chief Engineer, Detroit Electric Furnace Co.

SILVER BRAZING TUBES to Tube Sheets

By LEO EDELSON†

VARIOUS methods of attaching tubes to tube sheets are being used in industry today. Where it is found desirable to make joints of this kind by low temperature silver brazing the method described is recommended. It has proved entirely satisfactory and is far superior in many ways to methods used in the past.

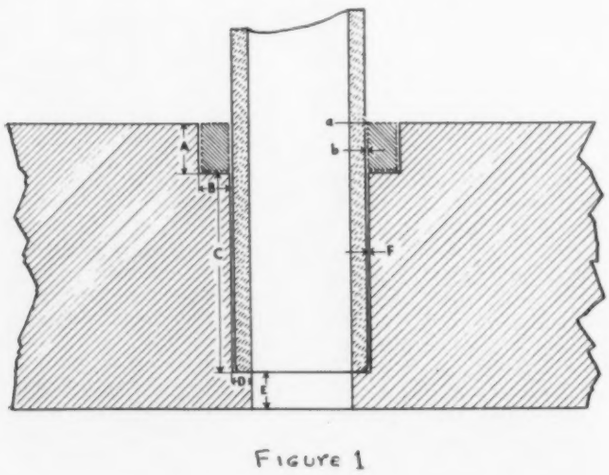


FIGURE 1

DESIGN

"A" & "B" dimensions in Fig. 1 indicate a recess for holding the Silver Brazing Alloy. These dimensions, of course, depend on the "C" dimension which governs the amount of alloy necessary in the ring to fill the shear area between the sidewall of the bored hole in the sheet and the tube. As a rule a rectangular alloy ring 0.050 inch thick and varying in width depending upon the size of the bore is suitable. In designing a joint of this type the top of the ring (*a*) should be level with or within a few thousandths of the top of the sheet. The inside diameter (*b*) of the ring should be about 0.003 inch larger than the outside diameter of the tube to permit easy assembling. This assures a fairly snug fit against the tube which helps in the transfer of heat when brazing.

Where the groove left by the melting of the silver brazing alloy is undesirable, the alloy recess should be so calculated that the alloy extends above the tube sheet and when melted forms a flush joint.

"C" This shows the depth of shear which is variable depending on the tube strength and suitable safety factors. A practical method of figuring shear depths is as follows:

X = (Unknown) = Depth of Shear

† Handy & Harman, New York.

D = Shear diameter
T = Tensile strength of weakest member
W = Wall thickness of weakest member
Y = Factor of Safety
L = Shear strength of silver brazing alloy
π = 3.1416

$$X = \frac{YTW}{L\pi D}$$

Example: Length of shear depth necessary when forming $^3/_4$–0.065 wall thickness copper tube to $^3/_4$ steel tube sheets.

X = Unknown
D = 0.75
T = 33,000 Annealed value copper
W = 0.065
Y = 10. (NOTE: This value is used on this particular job in that the thickness of the tube sheet lends itself to this factor. Where shear depths are limited a smaller safety factor will prove satisfactory.)
L = 25,000 psi shear value of silver brazing alloy. (NOTE: This is an arbitrary minimum value which can be expected from all silver brazing alloys containing appreciable amounts of silver.)

$$X = \frac{10 \times 33{,}000 \times 0.065}{25{,}000 \times 3.1416 \times 0.75} = 0.363 \text{ depth of shear.}$$

"D" Depends on the dimension of the tube wall thickness.
"E" Acts merely as a stop for the tube.
"F" Should give a clearance of 0.001 inch to 0.003 inch.

PROCEDURE

1. Cleaning.—Mechanically or chemically remove all dirt, oil, scale and oxides from the bored openings in tube sheet and ends of tube.

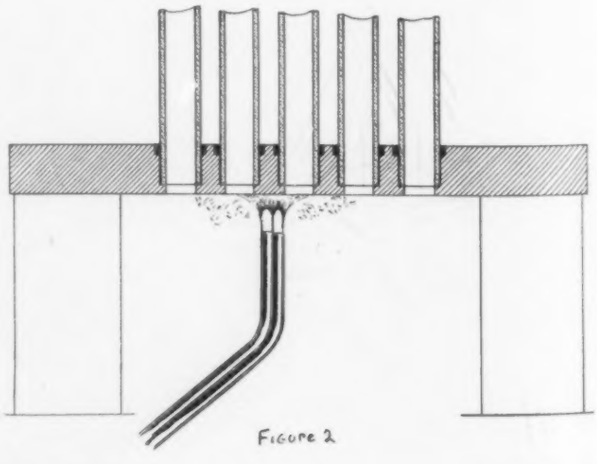


FIGURE 2

2. *Flux.*—Using a low temperature silver brazing flux—brush the tube ends with a coating of flux and also the bored opening.

3. *Alloy.*—If a copper to brass job—a silver phosphorous copper alloy which melts at 1300° F. may be used. If other combinations of metals, such as copper tube and steel header—steel tube to steel header and so forth, are being joined, a silver brazing alloy which melts at 1175° F. should be used.

4. *Insert alloy rings* in recess and flux—then place tubes in tube sheet.

5. *Heating.*—An oxyacetylene torch will effectively and rapidly heat this assembly although other means of heating may be employed. Proper attention to supporting the assembly while heating is essential. Heat should be concentrated while preheating on the tube sheet which is of heavier section. After a general preheating of the tube sheet the heat should be concentrated on the center of the tube sheet, until the alloy flows through, as denoted by a silver ring at the bottom of the tube. When this occurs the heat should be continued to the other joints, moving in a clockwise direction, until completion. At no time should the flame be concentrated on the tube, the tube being heated entirely by conductivity.

Close observance of the action of the flux will be of assistance in telling the temperature in the tube sheet. If the assembly is furnace heated placing small pieces of brazing alloy on the tube sheet will serve as a good temperature indicator. Allow the joint to cool slowly and before it falls below 300 to 400° F. immerse in hot water to remove flux and scale.

The advantages for this type of joint are:

1. Controlled cost of alloy is assured.
2. Controlled heat by visible inspection.
3. Unobstructed liquid passages. Streamline flow of liquids through tube with a minimum amount of turbulence gives long tube life since impingement is held to a minimum.
4. Since a very small area of brazing alloy is exposed to corrosion and since so much of the alloy is in the shear area in comparison to tube wall thickness if the unit is subject to corrosion the tube should fail far in advance of the joint. The joints are strong and ductile and are stronger than either the tubing or tube sheets under any physical test.

Meeting an Emergency

By GEORGE SYKES†

CAST-IRON WELDING SAVES $1500 AND FIVE WEEKS' PRODUCTION LOSS

THE recent plight of a box manufacturing company when a breakdown occurred in one of their main engines well illustrates the indispensability of the oxyacetylene process in times of major emergency. Production was immediately decreased 50 per cent, but, thanks to welding, the engine was back on the job in just seven days, including the time necessary to have a new casting made for one section of the steam chest that had been badly shattered. Had it not been for welding, the engine would have been out of service for six weeks.

STEAM CHEST BADLY FRACTURED

The engine was of the rocker valve type with a 24-in. bore piston and was the main power plant of the box company. A rupture in the cast-iron tee connecting the engine with the main steam line resulted in fracturing the steam chest in nine places.

A description of the installation will make it readily apparent just how the accident occurred. Attached to the center ring of the steam chest was an 8-in. line which connected with the cast-iron tee in the main steam line 20 ft. above the engine. Immediately above the steam chest was a large control valve, and midway between the top of the engine and the cast-iron tee was a large cast-iron steam separator. Thus, when the cast-iron tee ruptured while in operation at a pressure of 175 lb. per sq. in. the combined weight of the steam line, tee, valve and separator was applied directly to the top of the engine, causing the fracture of the steam chest.

An oxyacetylene service operator was called in to look over the job and suggest the best procedure for repair. Because of the number of breaks in the upper part of the steam chest, he felt that it would be advisable to have a special cover casting made which could be welded into position.

The necessary specifications for the casting were immediately drawn up and rushed to a foundry which was more than 150 miles away. The service operator followed to inspect the completed casting and then returned to direct the welding operation.

WELDED IN ELEVEN HOURS

The cylinder, steam chest and cover casting were first carefully preheated. Eleven hours of continuous cast-

Cast-Iron Welding Put This Engine Back in Operation at a Saving of $1500

† General Publicity Department, Union Carbide Company.

iron welding was then required to weld in the cover. When this was completed, the casting was reheated evenly and allowed to cool slowly.

The repair was completely successful, and, seven days after the request for help, the engine was back in service. The total cost was $550.00. A replacement head would have cost $2,000.00, plus installation costs. However, even more important than the actual dollar savings is the fact that replacement would have meant a 50 per cent production loss for a period of six weeks.

Repair on a Production Basis

By ALAN KELLOCK†

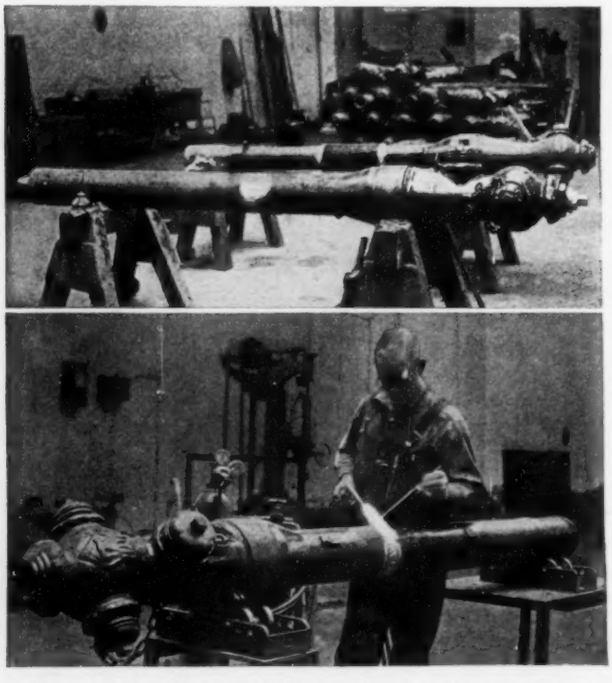
WATER HYDRANT REPAIR COSTS CUT BY USE OF JIGS

AN OLD story to many, but new to others, is the repair of water hydrants by bronze-welding. A new hydrant costs about $80.00. In years past, a damaged hydrant was worth about 50 cents as scrap. Today, it is reclaimed for a very small fraction of the cost of a new one. What makes such work of special interest is the fact that in at least one shop it has been set up to be done on a production basis in order to reduce the costs to the minimum.

HYDRANTS SET-UP ON DOLLIES

In the water works department of a city located in a cold climate, fractured hydrants are arranged on two tables which were fabricated by welding for this job. The tables are provided with dollies or rollers on which the hydrants can be turned to facilitate welding.

† General Publicity Department, Union Carbide Co.



(Top)—The Old Method for Setting-Up Hydrants for Bronze-Welding. (Bottom)—The New Method. Observe the Welded Tables and Dollies Fabricated for This Work

Damaged Hydrants, Now Repaired, Were Formerly Scrapped. This City Has Developed a Large Saving by Bronze-Welded Repairs

The hydrants are set up in the dollies and bronze-welded.

In some cases a length of pipe is used as a sleeve and bronze-welded to the remaining parts of the hydrant at each end. Occasionally, parts from two or more badly damaged hydrants on which individual repairs are impossible, are combined to make one good hydrant.

OTHER HYDRANTS LENGTHENED

Bronze-welding is likewise used to lengthen hydrants taken out of service in suburban districts. Many of these were installed before these districts were incorporated in the city and are shorter than standard. Instead of scrapping them, they are lengthened at a small cost, and placed in stock for further use as required.

Annual Meeting

Detroit

in conjunction with

Metals Congress Exposition

Oct. 17th–21st, 1938

Plan to Attend

STEEL PLATE FABRICATION in the Heavy Machinery Field*

By J. H. COOPER†

IN THE past few years the fabrication by welding of machine structures has found high favor especially with the manufacturer of special machines.

While it is true that structures fabricated of rolled steel are quite often given preference over cast iron or cast steel even in multiple units, usually the fewer the units the greater the economic advantage to be gained. Designers of special machines, of the "unusual" job, and of the "trial-horse" of the standard line which is being developed are turning to fabricated steel structures. In such designs certain data cannot be calculated with absolute assurance but must be obtained empirically from the structure itself and corrections made in the design. No type of manufacture lends its methods better to low first cost and flexibility for changes than does the fabricated machine base. No pattern charges need be absorbed by the one unit and any changes can be quickly and economically made with a gas-cutting torch and arc welding equipment.

The time of delivery of the special machine usually is at a premium as often the ultimate customer wishes to incorporate it in his production line to meet seasonal sales. This is particularly true of the automobile industry with its periodic retooling. Fabricating methods are at a particular advantage here as the delivery of the machine base is often made in the normal time required to make a pattern. Deliveries of two to four weeks are normal for the structures illustrated in this article, and in an emergency such a structure has been fabricated over a week-end. This short time, however, does not include a stress-relief anneal and shot-blasting, and is the exception to the average time.

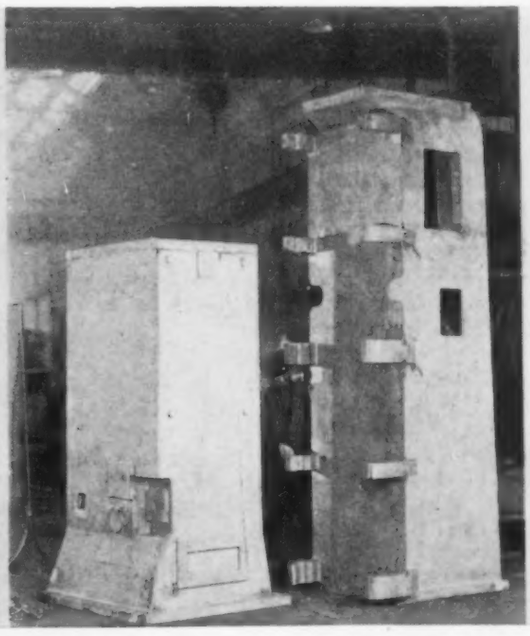
The unusual job where the predominating feature is a premium on weight reduction such as marine equipment for Navy contracts is particularly adapted to fabricating methods. Reduction of weight is accomplished over castings of steel or cast iron by the lack of limitations of the puring of thin sections of large area and thin sections in close proximity to thick ones. In a comparison with cast iron, wall sections may be thinned and ribbing eliminated due to the fact that rolled steel is twice as stiff as cast iron, as is shown by reference to their modulii of elasticity.

Whether the job is the single unit unusual one or the standard line, the question of a good economical finish is always important. A granular cast structure with no more than the normal run of sand spots, gas holes and checks, requires more filler coat than the rolled plate used in fabricated bases. Vibration in some cases makes heavy filler coats undesirable from a service standpoint. In the case of thin walled casings, guards, covers, etc., the use of "stretcher-leveled" sheet steel adds materially

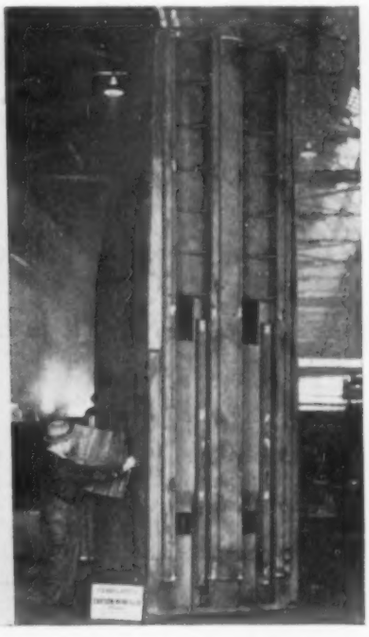
* Presented at October 6th Meeting, Detroit Section, AMERICAN WELDING SOCIETY.

† Welding Engineer, Fabricating Div., Taylor-Winfield Corporation.

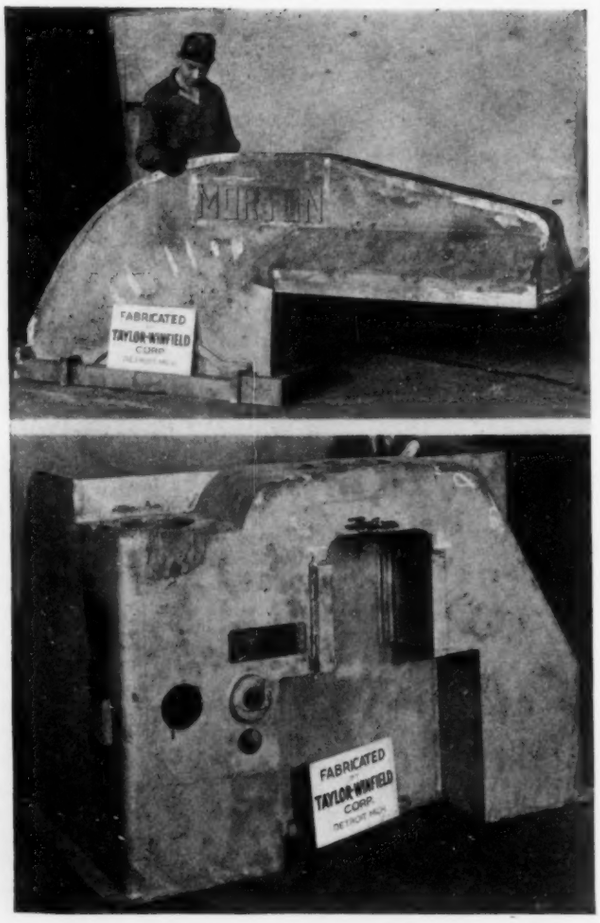
This Box Type Press Frame Takes Maximum Advantage of the Metal with a Minimum of Weld Metal. The Frame Is a Solid Piece Bent to Shape and the Shaft Bearings Are Inset So That the Weld Metal Used Is Not Directly Loaded but Merely Used for Locating the Bearings. Such an Open Type Frame Is Simple, Inexpensive and Practically Indestructible



Columns for Vertical Honing Machine Fabricated for Barnes Drill Company. Column on Right with Shaft Guides Is Assembled on Top of Column on Left. Weight of Each Column Is 6000 Lb. Photograph Shows Excellent Appearance of Columns When Assembled and Painted in Finished Machines



This Column for a Vertical Double Broaching Machine Is Typical of Vertical Broach Design. While This Column Weighs 13,000 Lb. as Fabricated for the LaPoint Machine Co., These Columns Vary in Size from a Few Feet High on Up and Are Built for Either Single or Double Broaches. The Ways are Premachined and Hydraulic Compartments Fabricated Inside



These Views of a Machine Base and Over-Head Ram Support Fabricated for the Morton Manufacturing Co. Are Typical of the Appearance After Fabricating and Shot-Blasting. The Units Are Heavy, 6300 and 3000 Lb., Respectively, but Care Is Taken to Round Corners, Use Simple Lines and Maintain a Smooth Surface Which Will Appear Well When Painted

to the final appearance and only a spray coat of paint is required.

A phase of welded steel construction which is gaining more and more attention of the designer is the one of premachining. Certain parts of the machine base may be more economically made by machining as separate units and then welded into the structure. A good example is the premachining done on the ways of the large vertical broach column illustrated in this article. These ways were clamped to the work table of a planer and "rough-out" leaving only $^1/_4$ inch finish. After welding into the structure only a minimum of material is left to be removed. Large internal bores or turnings can usually be more economically machined in a lathe down to a minimum of finish before final assembly in the machine base. Sections containing pipe or machine threads may be drilled and tapped before welding into place in positions inaccessible for machining after assembly or to give more thread bearing in thin walls.

These structures are given a stress-relief anneal after fabricating. Machine tool bases above all others can tolerate no "creep" after or during machining. The warping of castings due to the removal of the "skin" in machining may be avoided by using fabricated rolled plate. Lack of gates and risers permits the removal of less finish material.

In fabricating the structures illustrated, one of the important factors was the positioning of the work while welding. A majority of the welds were made with welds horizontal and the "throat" of the weld vertical. This insures best appearance, elimination of under-cutting, ability to use electrodes of maximum steel deposition efficiency, and the use of larger electrodes and higher welding currents.

Only heavily coated electrodes were used and all welding except tack welding at assembly was done with alternating current. Alternating current is particularly a benefit in improving the appearance and quality of the weld in corners.

It is important to have a proper control over welding bevels. The dimensions of the bevel should be carefully worked out and maintained to insure proper penetration to the root of the bevel to avoid unfused edges, gas pockets and slag inclusions which act as "stress-raisers." Yet bevels must not be too large as weld metal at 50¢ to $1.00 per pound as deposited is expensive and overly large bevels are a cause of excessive distortion.

No. 4030 Large Vertical Honing Machine. Left Three Quarter View. Machine Has 90 Inches of Spindle Travel, Is 31 Feet, 4 Inches High Over-All, as Here Shown, but the Height and the Spindle Travel May Vary Accordingly to Requirements. Also the Swing Could Be Varied Somewhat, but as Here Shown the Machine has 40 Inches of Swing, and Is Designed Strong Enough to Drive Hones Up to 30 Inches Diameter, but Which Would Require Perhaps a 50 Hp. Motor for Driving in Addition to a 15 or 20 Hp. Motor for the Hydraulic Pump System.

Floor Space Front to Back Is 172 Inches by 86 Inches Wide, Which Are the Dimensions of the Base. The Size of the Oil Operated Work Table, Working Surface 40 Inches x 60 Inches, and the Horizontal Travel of the Table in and Out on the Railroad Tracks Shown—50 Inches.

Machine as Here Shown Has 8 Quick Changes of Speeds Which Are: 12, 16, 22, 30, 39, 54, 72 and 98.

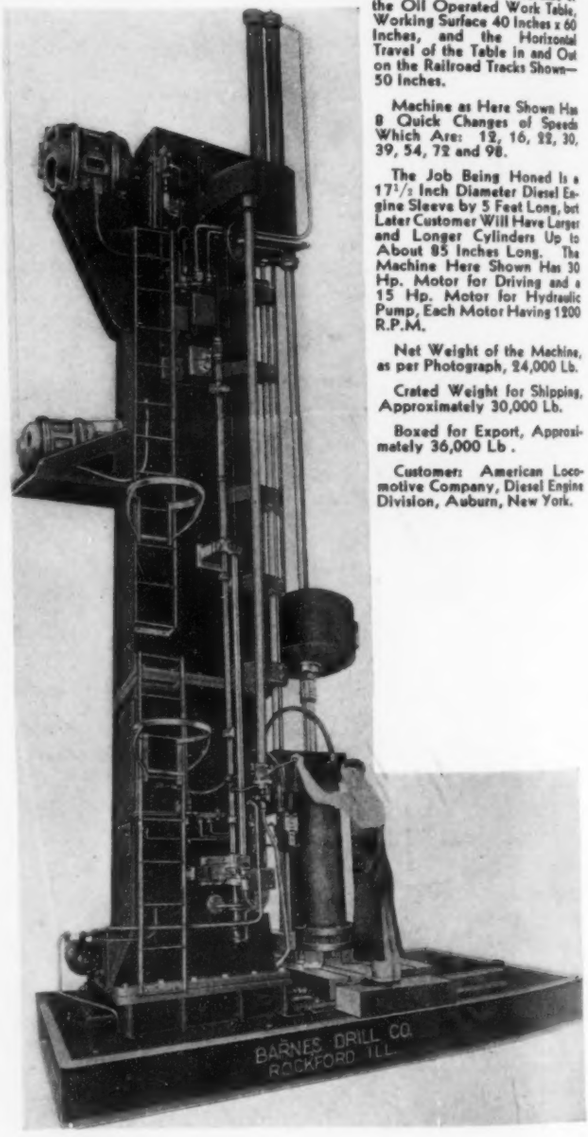
The Job Being Honed Is a 17½ Inch Diameter Diesel Engine Sleeve by 5 Feet Long, but Later Customer Will Have Larger and Longer Cylinders Up to About 95 Inches Long. The Machine Here Shown Has 30 Hp. Motor for Driving and a 15 Hp. Motor for Hydraulic Pump, Each Motor Having 1200 R.P.M.

Net Weight of the Machine, as per Photograph, 24,000 Lb.

Crated Weight for Shipping, Approximately 30,000 Lb.

Boxed for Export, Approximately 36,000 Lb.

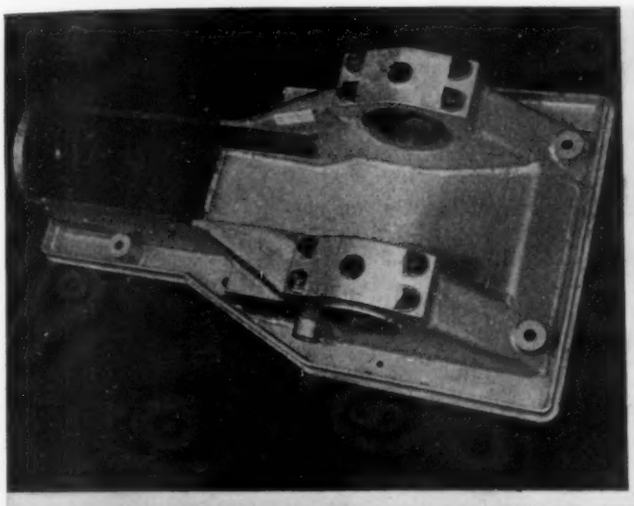
Customer: American Locomotive Company, Diesel Engine Division, Auburn, New York.



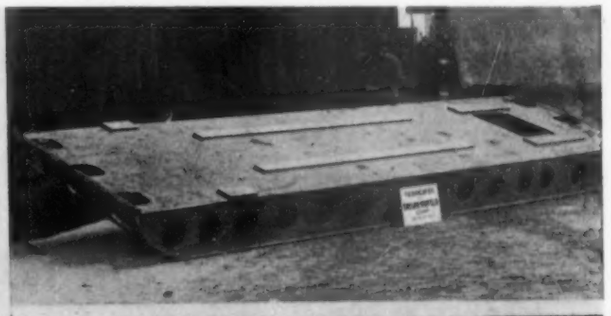
Such weld metal has average test values of 48–56,000 pounds per square inch yield point; 62–72,000 pounds per square inch ultimate tension; 28–33% elongation in 2 inches; 28–35-foot pounds Charpy impact; 27,000 pounds per square inch endurance limit and corrosion resistance equivalent to the clean, uniform silicon-killed low-carbon steel used. The steel as purchased is specified to be free of excessive scale and laminations and to have a maximum of 20% carbon with low impurities also specified.

Certain units of these structures such as bearing blocks over 10 inches thick can be more economically cast from cast steel than gas cut from rolled plate. Other compact heavy parts with compound curves should be reduced to simple steel castings, sometimes cast with welding bevels. Such castings may be incorporated in the composite structure for maximum economic gain. The experienced designer soon recognizes the features of a particular point in the structure which should be cast steel and welded into the assembly or adapted to rolled plate and standard section shapes.

Expansion Engine Base for National Cylinder Gas Company, Weight, 1335 Lb. Designed for Dynamic Loading and Minimum of Machining Costs



Skid for Portable Power Plant for Use in Oil Fields. Weight, 9000 Lb. as Fabricated for the Sterling Engine Company. Load of Power Plant, Including Engineer, Generator, Radiator and Auxiliaries to Be Ten Tons



This Hydraulic Pump Base Indicates the Ease with Which Rolled Plate May Be Broken Up into Box Sections and High Rigidity Obtained with Simple Lines and No Unsightly and Expensive Ribbing. Pads and Bearings All Have Only ¼-Inch Finish

The Upper, Center and Lower Gear Housings for Rolling Mill Machinery as Fabricated for Kent-Owens Machine Company. Weight, 2675 Lb. The Bearing Blocks Are Gas-Cut from Rolled Plate Leaving a Minimum of Finish to Be Machined. Support Plates Beneath Each Bearing Transmit the Load Directly to the Base Plate, and "C" Ribs Over the Top Strengthen the Upper Housing Against Side Thrust. All Welding and Joint Preparation Is of a Quality Required for Dynamic Loading

WELDING HANDBOOK

The world's leading authoritative Welding Handbook will probably be available some time in April. It contains 800 pages of reliable information. More than 70 outstanding welding experts contributed chapters to this Handbook which in turn were reviewed and revised by more than 300 other experts. In other words, more than 350 people have contributed to the information contained in this book.

Price to non-members $6.00 per copy.

STANDARDIZATION OF MATERIALS for Coated Electrodes

By GORDON H. CHAMBERS†

HEAVY coatings on welding electrodes entered the the field about twelve years ago and definitely gave arc welding its present fine reputation. In addition to furnishing a dielectric covering for the rod, these coatings must have many other peculiar properties in order to govern the stability of the arc, the melting rate of the rod, the character of the slag and the properties of the weld metal. The coated electrode must be uniform in respect to each of these various functions. Consequently the production of good coated rods is more difficult than, for example, that of extruding the rubber cover on a copper cable or fitting porcelain enamel to steel.

As a matter of fact, welding rod metallurgists in Europe and America until recently have had no clear understanding of the complex functions which the coating was supposed to perform in arc welding. The industry grew so rapidly that it got far ahead of the scientific theories on which it is based. Like Topsy, the manufacture of coated electrodes "just growed" and there was little time for basic research or scientific literature. However, some of the more progressive companies in the welding field are now conducting fundamental research on rod coatings and some day we will have exact knowledge of the effect of various factors on the arc, the weld metal, the slag and the extrudability of the coating. When that point is reached, the job of welding metallurgist will be as prosaic as that of a laboratory boy in an open-hearth steel plant. At the present time however it requires a highly trained technologist with a knowledge of electrical engineering, ceramics, mineralogy, metallurgy, plastics, mechanics and physics.

Suppliers of many of the products used in steel, aluminum and hard surfacing welding rods, have found that there were no complete specifications on these raw materials. To remedy this condition a welding rod laboratory was organized by one supplier to develop new coating ingredients and conducted control tests on the many welding materials produced. In spite of careful physical controls and chemical analyses on each batch, certain variations occurred in the behavior of these products and indicated the necessity of also making welding tests. For example, two samples of manganese dioxide from different mines may both contain 85% MnO_2 and be ground to the same fineness but, in a standard rod coating, one will have 20% more welding speed than the other. The most direct way to check such variations is with actual welding. The laboratory was therefore equipped with a specially designed extruding machine and other equipment necessary to produce coated rods. These experimental electrodes are comparable to the better commercial rods on the market in performance, and they enable the laboratory to report accurately on slag characteristics, splatter loss, ductility of the weld metal and other factors.

Every one connected with the welding industry realizes that suppliers should furnish definite information regarding their materials and it is suggested that electrode manufacturers cooperate by adopting better raw material specifications which would clearly emphasize differences in the governing characteristics of each coating ingredient. In establishing these specifications, the following factors should be considered.

1. Impurities Detrimental to the Weld Metal

(*a*) There should be maximum limits on sulphur, phosphorus, antimony, tin and several other elements.

(*b*) In some types of welding a high metallic silicon content is bad and therefore a maximum limit on silicon should be established, for example on ferromanganese and tungsten metal powder.

(*c*) Some elements affect the surface tension of aluminum and steel and must therefore be limited.

(*d*) There should be minimum and maximum limits

† Vice-President of the Foote Mineral Company.

Fig. 1—Chemical Control in the Laboratory

Fig. 2—A Rotap Screen Testing Machine Used to Determine Particle Size

Elutriator Is Used to Measure Fineness and Insure Uniformity

Fig. 3—Many Coating Materials, Such as Titanium Dioxide, Lithium Fluoride and Airfloated Rutile, Are Too Fine for Accurate Screen Analysis

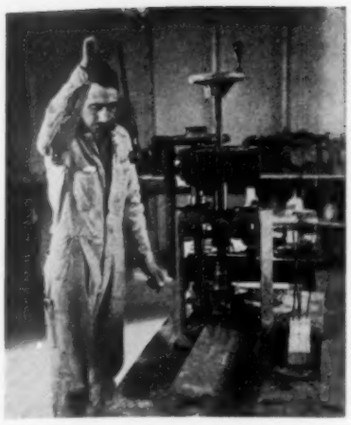


Fig. 4—Extruding Coated Electrodes in the Laboratory

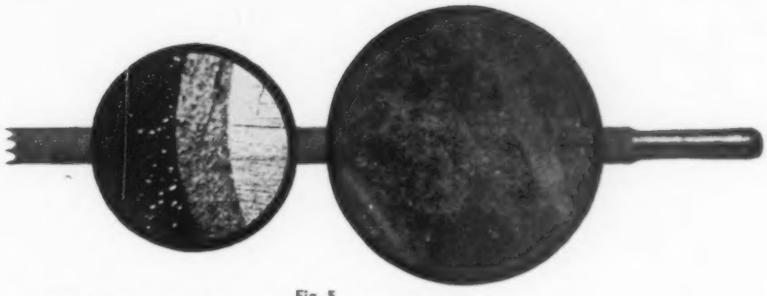


Fig. 5
Cross Section of Coated Rod Showing Thickness of Coating — Polished Section of Coating Magnified 125 Diameters

on carbon and elements which affect either the hardness or tensile strength.

2. Impurities Which Affect Slag Characteristics Such as

(*a*) Fluidity.
(*b*) Viscosity.
(*c*) Surface Tension.
(*d*) Slag Removal.
(*e*) Surface on the Weld Metal.

3. Color and Other Physical Factors

(*a*) A uniform color is desirable from a sales standpoint and color specifications must, therefore, be established.

(*b*) Hygroscopic coating materials are impractical so that this factor must also be considered.

(*c*) Crystal structure must be known as it not only has an effect on arc stability but also on the appearance and strength of the coating. For example, a fused, glassy titanium dioxide will not give the same coating as a light porous type.

4. Particle Size

(*a*) Effect on arc stability.
(*b*) Effect on uniformity of the coating.
(*c*) Effect on extrudability of the coating.

The wide range of particle sizes in a good coating is exemplified in Fig. 5 which shows a typical all-position coated rod, magnified 125 diameters. The large black particles are granular ferromanganese, the long, white fibrous particles are amphibole asbestos and the many small grey particles are air-floated rutile. The white background is clay and the sodium silicate binder. This coating also contains cellulose but it does not show clearly in this photomicrograph.

5. Impurities Which Affect the Arc

There are certain elements which have very strong thermionic emission at a given temperature. Although they may be quite advantageous in, for example, a bronze rod, the same element may reduce the speed of a steel rod. So there must be limitations on these impurities.

It would be difficult and probably impossible to check all of these factors on each batch of a certain coating material. However, reasonable specifications on chemical analysis and particle size and a carefully controlled standard welding rod test will provide a check on most of these characteristics.

The chemical specifications are not difficult to draw up but some welding metallurgists have neglected to establish definite maximum limits on impurities. The same situation exists in many cases on screen specifications but these things can be easily remedied. The chief problem is to devise a standard welding test for each raw material. After all, the only purpose of these specifications and tests is to produce a good welding electrode. Therefore, current practice among rod manufacturers tends toward the most direct type of test. If they happen to receive a new shipment of iron oxide, they simply use a sample of this new lot in a standard coating formula and make a welding test. But if there is only 5% iron oxide in that particular coating, the test is almost meaningless. Our thought is that the iron oxide or any other coating material should be tested in a special coating formula which will accentuate differences either from batch to batch or

Fig. 6—Typical All-Weld-Metal Tensile Test Specimen

RESEARCH LABORATORY
WELDING ROD COATING REPORT

TEST NO.	ROD NO.	PLATE NO.	DATE WELDED
SIZE BARE ROD	DIE SIZE	MATERIAL TESTED	
CURRENT AMPS—VOLTS	POLARITY	POSITION PLATE	TYPE WELD
WGT. PLATE IN GMS. BEFORE		FLUX ANALYSIS	
WGT. PLATE IN GMS. AFTER			
WGT. ROD IN GMS. AND %			
WGT. FLUX IN GMS. AND %			
WGT. ENDS IN GMS. AND %			
WGT. DEPOSIT IN GMS. AND %			
WGT. SPLATTER IN GMS. AND %			
ARC. TIME IN SECONDS			
BURNING RATE PER ROD IN SECS.			
DEPOSIT RATE LBS. PER HOUR			
SHAPE OF BEAD	UNDERCUTTING	WELD METAL PHYSICAL TESTS	
GENERAL PERFORMANCE		SIZE BAR	AREA IN SQ. INCHES
TYPE OF ARC		YIELD POINT P. S. I. IN LBS.	
NATURE OF SLAG		STRAIN P. S. I. IN LBS.	
		ELONGATION IN 2 INCHES IN %	
		REDUCTION OF AREA IN %	
WELDER		DENSITY IN GMS. PER C. C.	
REPORT BY	DATE	IMPACT IN LBS.	
		FREE BEND IN %	

(REMARKS—OVER)

Fig. 7—Report Form Used in Making Welding Tests on Raw Materials

between two sources of supply. Would it not be possible to agree on a standard welding test for each type or general classification of raw material? This would involve:

(*a*) Devising a special formula which would accentuate differences in quality.

(*b*) Making duplicate sets of coated rod with this formula, in one case using a standard sample and in the other a sample of the new batch.

(*c*) After the rods are extruded and dried they would be tested with a definite welding technique. This involves specifying such details as current, polarity and position on the rod.

(*d*) The results of this weld test may be used to show speed or rate of deposit, splatter loss, shape of weld bead and all of the slag characteristics.

(*e*) If the raw material has an important bearing on the physical properties of the weld metal, it would be necessary to agree on a standard test to measure tensile strength and ductility.

It is apparent that the present specifications and welding tests on coating materials are open to further improvement and electrode manufacturers have already shown a willingness to help improve them. But the above outline indicates that a great many factors must be checked to definitely establish that a batch of coating material is uniform in all respects. A few tenths per cent of certain impurities in a reverse polarity rod may reduce the welding speed 40%, a slight change in carbon content may have a marked effect on splatter loss and in some coatings even a small difference in the iron content will spoil the slag characteristics. The coating performs so many critical functions that the control of quality is correspondingly complicated.

INDEX TO ADVERTISERS

Air Reduction Sales Company ..... Outside back cover
Aladdin Rod & Flux Mfg. Co. 52
American Brass Company 49
American Society for Metals 54
Anti-Borax Compound Company 50
Bastian-Blessing Company 51
Bulletins 50
F. R. Faulk 51
Foote Mineral Co. 52
General Electric Company ..... Inside front cover
Krembs & Company 52
Lincoln Electric Company ..... Inside back cover
The Linde Air Products Company 2
P. R. Mallory & Co. Inc. 50
McKay Company 48
Metal & Thermit Corporation 53
National Carbide Corporation 51
John A. Roebling's Sons Co. 56
Safety Equipment Service Co. 50
Thomson-Gibb Electric Welding Company 51
Union Carbide and Carbon Corp. 2
Victor Equipment Company 55
Weldit Acetylene Company 52
Wooldridge Aluminum Welding Products 51

WELDING SOCIETY ACTIVITIES
AND RELATED EVENTS

Western Regional Conference

The Western Regional Conference of the AMERICAN WELDING SOCIETY will be held at the Biltmore Hotel, Los Angeles, March 21st to 25th. The meeting is to be held in conjunction with the American Society for Metals and the Western Metals Congress.

All the Pacific Coast Sections of the Society are working together to make this Conference a success as the estimated attendance of the Western Metals Congress is about 50,000. All those interested in the science and art of welding are invited to attend. Copy of the advance program is reproduced below.

Mr. Wayne Howard one of the prime factors in promoting this conference is Chairman of the Program Committee. Technical papers include Oil Well, Pipe Lines, Fabrication, Pressure Vessels, Stainless Steel, Hard-facing, Inspection and other phases of welding industry.

Mr. E. F. Scattergood, Chief Electrical Engineer and General Manager of the Department of Water & Power, is giving his active support as General Chairman of the Western Regional Conference. Mr. Scattergood has been closely connected with some of the largest welded pipe line constructions in the west. The Department of Water & Power is one of the largest users of welding in the Pacific Southwest.

Other members of the Conference Committee include:

Registration Chairman—Merrill E. Turner, Home Oxygen Co.

Entertainment Chairman—H. P. Etter, Air Reduction Sales Co.

Secretary—J. C. Gowing, J. C. Gowing Company.

Publicity Chairman—E. O. Williams, Victor Welding Equipment Co.

This Committee is aided by the Western Division Officers, consisting of:

Divisional Vice-President—K. V. King, Standard Oil Co. of Calif.

San Francisco—N. F. Ward, Section Chairman; University of Calif.

Los Angeles—P. D. McElfish, Section Chairman; Standard Oil Co. of Calif.

Montana—H. F. C. Rumfelt, Section Chairman; Fort Peck.

Hawaii—E. E. Heacock, Section Chairman; Hawaiian Gas Products Co.

San Joaquin Valley—B. Rintoul, Section Chairman; Western Water Co.

Portland—G. C. Dierking, Section Chairman; Steel Tank & Pipe Co.

Advance Program
for the
AMERICAN WELDING SOCIETY
Western Regional Conference
Los Angeles, California, March 21st, 22nd, 23rd, 24th and 25th, 1938
BILTMORE HOTEL

In Conjunction with the American Society for Metals and the Western Metals Congress and Exposition

Conference Sessions, 9:00 A.M. to 12 Noon, Biltmore Hotel.

Metals Exposition—Pan-Pacific Auditorium, 12 Noon to 10:00 P.M.

Registration—Biltmore Hotel and Exposition Hall. No Registration Fee.

Luncheon Meeting of Divisional and National Representatives, Dinner Dance, Inspection Trips, Ladies Entertainment and a Pleasant Visit to Sunny Southern California.

Make room reservations directly with Hotel Biltmore.

Members and Guests are urged to register early. Admission to the Metals Exposition will be by Convention Badge only.

Monday, March 21st

9:00 A.M. OPENING SESSION

P. D. McElfish, Chairman, Standard Oil Co. of Calif., Presiding.

T. C. Smith, Vice-Chairman, General Petroleum Corporation.

Announcements

Symposium on Welded Oil Well Casing Strings

Weldability and Properties of Materials for Casing String, Mr. Isaac Harter, Babcock & Wilcox Co.

Field Practice in Welding Casing Strings, Mr. Howard Newby, Superintendent, American Pipe & Steel Corp.

Physical and Economical Advantages of Welded Casing Strings, The Shell Oil Company.

12:00 NOON LUNCHEON MEETING

K. V. King, Divisional Vice-President, Presiding.

Los Angeles Harbor, Showing Outer Harbor. In distance—Inner Harbor, West Basin and Los Wietos Channel

Biltmore Hotel—Headquarters for American Society for Metals Congress

Welcoming Address, E. F. Scattergood, Convention Chairman.
Introduction of National & Divisional Officers by Mr. King.
Address by Mr. P. G. Lang, Jr., *President* of the AMERICAN WELDING SOCIETY.

12:00 NOON to 10:00 P.M.
Metals Exposition, Pan-Pacific Auditorium.

Tuesday, March 22nd

9:00 A.M. CONFERENCE SESSION
John McCone, Chairman, Bechtel-McCone Corporation.
C. W. Roberts, Vice-Chairman, Southwestern Engineering Co.
Design and Fabrication of High Temperature and High Pressure Piping.
F. C. Fantz, The Midwest Pipe & Supply Co.
Reconditioning Existing Pressure Vessels to Meet Present Day Safety Standards.
K. V. King, Standard Oil Company of California.
Stainless Alloy Welded Plate and Castings Combined in Corrosion Resisting Pressure Equipment.
Richard Jameson, Electric Steel Foundry Co., Portland, Ore.
Welded Plate Construction for Machinery Bases and Substructures.
Richard Young, Bethlehem Steel Company.

12:00 NOON to 10:00 P.M.
Metals Exposition, Pan-Pacific Auditorium.

Wednesday, March 23rd

9:00 A.M. CONFERENCE SESSION
C. M. Allen, Chairman, Los Angeles Bureau of Light & Power.
C. P. Sanders, Vice-Chairman, Western Pipe & Steel Company.
Symposium on Large Welded Pipe for Water & Power Transmission.
Design of Large Welded Pipe, Laterals and Supporting Structures.
Dr. W. F. Durand, Stanford University.
Shop Fabrication and Spinning of Protective Coating.
L. M. Muffler, Consolidated Steel Corporation.
Field Erection and Inspection.
Southern California Metropolitan Water District.

12:00 NOON LUNCHEON CONFERENCE
Memberships, programs and organization problems of the Society and of the Sections will be discussed.

12:00 NOON to 10:00 P.M.
Metals Exposition, Pan-Pacific Auditorium

Thursday, March 24th

9:00 A.M. CONFERENCE SESSION
R. W. Binder, Chairman, Bethlehem Steel Company.
O. G. Bowen, Vice-Chairman, Consulting Structural Engineer.
Design of Welded Connections in Building Construction.
Paul Jeffers, Consulting Structural Engineer.
Resistance Welding Processes and Their Application.
Stanley Levyne, Acme Electric Welder Company.
Problems in Welding Light Gage Materials.
Linde Air Products Company.

12:00 NOON to 10:00 P.M.
Metals Exposition, Pan-Pacific Auditorium.

7:00 P.M.
Dinner Dance
Biltmore Bowl, Biltmore Hotel.

Friday, March 25th

9:00 A.M. CONFERENCE SESSION
N. F. Ward, Chairman, University of California.
Lloyd Earl, Vice-Chairman, Consolidated Steel Corporation.
Application and Proper Use of Hard-Facing Materials.
Don Llewellyn, Air Reduction Sales Company.
Characteristics of Slags, Their Application to Electrode Composition and Effect on Welding.
Dr. Welton J. Crook, Stanford University.
Welding Cast Irons.
Professor Gilbert S. Schaller, University of Washington.
Helping the Small Job Shop Welder.
J. C. Gowing, J. C. Gowing Company.
Inspection of Welds and the Supervision of Welding Operators.
Russell Graves, Union Oil Company of California.

12:00 NOON to 10:00 P.M.
Metals Exposition, Pan-Pacific Auditorium.

Western Metal Congress

With the AMERICAN WELDING SOCIETY meeting in Los Angeles at the same time, the Western Metal Congress and Exposition, March 21 to 25 in the Pan-Pacific auditorium and Biltmore hotel, is expected to attract 3000 executives, plant operators, metallurgists and superintendents to the Congress and many thousands to the exposition.

Both events, the Congress and the Exposition, will be based on the theme, "Metals in Industry."

The Exposition, held in Los Angeles eight years ago, was attended by 60,000, but William H. Eisenman, secretary of the American Society for Metals, said an earnest effort will be made to eliminate the curiosity seeker and to attract only 25,000 interested men, who are definitely connected with the fabrication of industrial metals.

Eighteen national technical societies are cooperating in the double event.

These are:

AMERICAN WELDING SOCIETY, American Chemical Society, American Foundrymen's Association, American Institute of Aeronautical Engineers, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers (Institute of Metals), American Petroleum Institute (California division), American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, Chamber of Mines and Oils, Metal Trades and Manufacturers' Association, Mining association of the Southwest, National Purchasing Agents' association, Pacific Coast Electrical Association, Pacific Coast Gas association, Society of Automotive

Engineers and the American Society for Metals.

Other organizations than the AMERICAN WELDING SOCIETY, which will meet independently in their own sessions during the week of the Congress and Exposition, are the American Society of Mechanical Engineers and the Pacific Coast Gas Association.

Particular attention will be paid by the Congress to metals used in the petroleum, aviation, general manufacturing, chemical and mining industries. Speakers from all parts of this country will participate in the educational program.

A series of five educational and informative lectures on the manufacture, treatment and application of iron and steel will be presented by Dr. A. Allan Bates, distinguished lecturer, teacher and researcher, who formerly was professor of metallurgy, Case School of Applied Science. Dr. Bates now is manager of the chemistry and metallurgical department of Westinghouse Electric and Manufacturing Company, Pittsburgh.

Wives, who accompany their husbands to the Congress, will find a brilliant program of entertainment arranged for their enjoyment. This program will include visits to movie studios, Huntington Library, Pasadena, Santa Monica, Beverly Hills and other points of interest, as well as a series of lunches and the banquet of the convention in the Biltmore Bowl.

1938 Nominating Committee

In accordance with the By-Laws President Lang has appointed the following members to serve as the 1938 Nominating Committee.

F. M. Farmer, *Chairman;* Electrical Testing Labs., 80th St. & East End Ave., New York City.

A. G. Oehler, Simmons Boardman Pub. Co., 30 Church Street, New York City.

T. M. Jackson, Sun Shipbuilding & Dry Dock Co., Chester, Pa.

Jonathan Jones, Bethlehem Steel Co., Bethlehem, Pa.

J. W. Owens, Fairbanks, Morse & Co., Beloit, Wis.

E. C. Chapman, Combustion Eng. Co. Inc., Hedges-Walsh-Weidner Div., Chattanooga, Tenn.

N. F. Ward, University of California, Berkeley, Calif.

This Nominating Committee is to select candidates for the following positions.

President—Term of one year.

Senior Vice-President—Term of one year.

Divisional Vice-Presidents—New York and New England, Middle Eastern Division, Middle Western Division (term of two years).

Of these, the President and Senior Vice-President are eligible for re-election.

The Nominating Committee must also select 5 Directors-at-large for a term of three years, to fill the vacancy of Messrs. C. A. Adams, E. Chapman, H. M. Hobart, F. T. Llewellyn and H. L. R. Whitney, whose terms expire. All of these Directors are eligible for re-election.

The purpose of announcing the appointment of the Nominating Committee in the JOURNAL is to provide every member of the AMERICAN WELDING SOCIETY an opportunity to write to one or more of these members of the Nominating Committee offering their suggestions.

The By-Laws provide that the Nominating Committee shall deliver to the Secretary in writing on or before the last Tuesday in May, the names of its nominees for the various elective offices next falling vacant together with the written acceptance of each nominee. It is, therefore, desirable that suggestions be sent to the Nominating Committee sometime in February or early in March (preferably before March 15th).

Committee on Outline of Work

In the January issue there was announced the favorable action of the organization of a Committee on *Outline of Work*. At a meeting of the Executive Committee held on January 18th the following members were appointed on this Committee.

H. C. Boardman, *Chairman*
A. G. Bissell
G. F. Jenks
K. V. King
S. S. Scott
W. Spraragen, *Secretary*

Representatives on Other Societies

The following representatives were appointed on other Societies.

A. S. A. Sectional Committee on Electric Welding:

W. W. Reddie, representatives
R. S. Donald
L. D. Meeker, alternates
H. A. Woofter

Members Executive Committee

At a meeting of the Executive Committee held in New York on January 18th, the appointment of Messrs. H. C. Boardman and A. G. Oehler as members of the Executive Committee of the Society, were approved. The membership of the Executive Committee as now constituted is:

P. G. Lang, Jr., *Chairman*
C. A. Adams
H. C. Boardman
J. J. Crowe
J. H. Deppeler
A. E. Gibson
G. F. Jenks
M. M. Kelly, *Secretary*
L. R. Leveen
F. T. Llewellyn
C. A. McCune
A. G. Oehler
W. W. Reddie
H. S. Smith

Board of Award

This year the Board of Award will have in charge the selection of recipients of the Miller Memorial Medal and the Lincoln Medal. At a meeting of the Executive Committee held in New York on January 18th, Mr. G. T. Horton was appointed to fill a vacancy. The members of the Board of Award are now:

H. L. Whittemore, *Chairman*
G. T. Horton
A. G. Oehler

The Samuel Wylie Miller Memorial Medal is awarded annually for meritorious achievement which in the judgment of the Board has contributed conspicuously to the advancement of the art of welding and cutting.

The Lincoln Gold Medal is given annually for the best paper presented before a Section or National Meeting that has contributed most to the development and advancement of welding and published in the AMERICAN WELDING SOCIETY JOURNAL.

The William B. Pollock Company

The AMERICAN WELDING SOCIETY is in receipt of a bronze medal to commemorate the 75th Anniversary of the founding of The William B. Pollock Company.

The obverse of the medal depicts a Blast Furnace engineered, fabricated and erected recently by the Pollock Company, and the reverse shows a modern Pollock Hot Metal Car. Although The William B. Pollock Company is known to every Industry that requires Steel Plate Construction, the Steel Industry by way of the Blast Furnace was chosen for the medal because in that field it has been most outstanding. The Hot Metal Car was also chosen from the steel making industry because the Pollock Company is so well known for that product.

International Engineering Congress

The International Engineering Congress will be held in Glasgow June 21st to 24th, 1938. The AMERICAN WELDING SOCIETY has been invited to appoint two official delegates to the Congress. Any member of the AMERICAN WELDING SOCIETY who is planning to attend will kindly communicate with the Secretary in order that consideration may be given to their appointment as official delegates of the Society.

Progressive Welder Pamphlet

A very interesting pamphlet on Hydraulic Punching units has been prepared by the Progressive Welder Company. This pamphlet also describes the new Resistance Welders of this Company.

McKay-Arcos Co.

The McKay Company of Pittsburgh, Pennsylvania, announces the appointment of the Arcos Corporation, Philadelphia, as distributor for McKay Arc Welding Electrodes in a territory comprising eastern Pennsylvania, southern New Jersey, Delaware, Maryland and Virginia.

Photoelasticity

Theory and Practice

(A Textbook for Students and Engineers)

By ARSHAG G. SOLAKIAN

Lecturer, Columbia University, New York, N. Y.

The lecture notes of the author, as presented to the Civil and Mechanical Engineering Students of Columbia University in the past several years, will be published in *Photoelastic News* under various headings, beginning with the first issue in January 1938. These notes in a revised form will later be available for us as a textbook. Publication expected on or before August 1938. Price per copy (postpaid), $2.50; Photoelasticity with Photoelastic News $4.00. Published by Polarized Light Co., 55 West 42nd Street, New York, N. Y.

Photoelastic News.—A monthly publication dealing with stress, polarized light and plastics, volume 1, January 1938, No. 1. Editor, Arshag G. Solakian, Lecturer, Columbia University, New York, N. Y. Subscription, $2.00 per year.

Contents for January

1. Editorial
2. Historical Development of Photoelasticity
3. Stress-Strain Relations
4. Polarized Light and Applications
5. Plastics Used in Photoelasticity
6. Photoelastic Models with Cemented Elements
7. Recent Publications in Photoelasticity
8. News of Interest

John A. Capp

John A. Capp, engineer of materials in the General Electric Works Laboratory at Schenectady, died January 6th after a short illness. He would have been 68 years of age on January 14th and was a veteran of more than 45 years' service with the Company.

Mr. Capp was born in Philadelphia in 1870 and as a student at Central High School there, he was a pupil of the late Professor Elihu Thomson, with whom he was later associated in the Thomson-Houston Company, a predecessor of the General Electric Company, at Lynn, Mass. Mr. Capp was graduated from the University of Pennsylvania in 1891 and after a short time at Lynn, was sent to Schenectady. He formed the testing laboratory and was its head until it was merged with the Schenectady Works Laboratory in 1927. During his service with the Company he specialized in the study of many types of materials entering into the construction of electric equipment.

As a charter member of the American Society for Testing Materials he has been active in its work since 1898. He was president in 1918 and 1919, and last year was elected an honorary life member of the organization. He was instrumental in the formation of the American Standards Association, and for many years represented the A. S. T. M. with the standards group.

Mr. Capp was a member of the American Foundrymen's Association and for many years was active in the AMERICAN WELDING SOCIETY.

Year Book Error

Our attention is called that in the Year Book of the AMERICAN WELDING SOCIETY, Mr. F. G. Hibbard of the Milwaukee Electric Railway and Light Company, title is given as "Efficient Engineer of Ways and Structures." This title should have been "Assistant Engineer of Way and Structures."

Our sincere apologies to Mr. Hibbard. The name was added to the directory at the last minute by long distance telephone and apparently "Efficient" and "Assistant" sounded the same.

Albert Reichmann Retires

Albert Reichmann, 600 Central Avenue, Wilmette, Illinois, who supervised the designing of many of America's largest steel structures, including those for the world's largest steel mills at Gary, Indiana and South Chicago, Illinois and the giant steel ore docks at Duluth and Two Harbors, Minnesota, retired from the American Bridge Company. He will reach the United States Steel Corporation retirement age of seventy on January 16, 1938.

Mr. Reichmann, who is one of the most widely known Civil Engineers in the United States, has been Vice-President of the Bridge Company since 1935. He has been connected with this subsidiary of the United States Steel Corporation since the Corporation was organized in 1901.

During the past thirty-six years, while he was in charge of the Engineering Department of the Western Division, his Company has furnished the structural steel for numerous outstanding structures, notably the San Francisco-Oakland Bay Bridge; the Willamette River Bridge, at Portland, Oregon; the Thebes Bridge over the Mississippi River; the Board of Trade, the Daily News and the Tribune buildings; the Union Station, the Stevens Hotel, the Palmer House, the New Post Office and the Michigan Avenue and the Outer Drive Bascule Bridges, in Chicago.

Mr. Reichmann was born in Dubuque, Iowa, and received his engineering education in Germany. He began as a draftsman with the Lassig Bridge & Iron Works in October 1890, and in 1891, came to the American Bridge Works as a draftsman and computer. In 1894, he became Assistant Engineer in charge of design, Bridge and Building Department of the Chicago, Milwaukee & St. Paul Railroad Company; and in 1901, he joined the American Bridge Company as Division Engineer. He was appointed Assistant Chief Engineer of the Bridge Company in 1931, and elected Vice-President in 1935.

Mr. Reichmann served as a Director of the American Society of Civil Engineers from 1929 to 1931, as Treasurer of the Western Society of Engineers from 1906 to 1913, and as President from 1913 to 1914. He is also a member of the American Railway Engineering Association, the American Iron & Steel Institute, the AMERICAN WELDING SOCIETY, the American Society for Testing Materials, the Chicago Association of Commerce, the Union League Club, the Chicago Engineers' Club, the Academy of Political Science and the Westmoreland Country Club.

Riehle to Manage Welding Sales

The Harnischfeger Corporation of Milwaukee announces the recent appointment of Mr. Abbott F. Riehle to the position of Sales Manager of the Smootharc Welder and Welding Electrode Division.

Mr. Riehle comes to the Harnischfeger Corporation with a wealth of managerial and sales experience as a background to insure his success in his new position.

A graduate of the University of Pennsylvania with a degree of mechanical engineering, Mr. Riehle for ten years was in charge of the sales and management of the Riehle Brothers Testing Machine Company of Philadelphia, which was later taken over by American Machine and Metals, Incorporated, where he continued in charge of sales.

Professor Wilson Honored

The Western Society of Engineers awarded the Chanute Medal to Professor W. M. Wilson of the University of Illinois for his paper on "Present Status of Structural Welding."

Members of the AMERICAN WELDING SOCIETY and particularly the Fundamental Research Committee will join us in congratulations to Professor Wilson.

1938 Foundry Convention

The 42nd Annual Convention of the American Foundrymen's Association will open Monday morning, May 16th, and continue four days to include Thursday, May 19th, with the Foundry Show opened in advance for inspection on Saturday, May 14th. The meetings and exhibits will be held in spacious rooms and exhibit halls connected with the Cleveland Public Auditorium.

The program of meetings will be extensive with 35 sessions comprising management, technical, production and shop practice sessions and round table conferences relating to steel, malleable, nonferrous and gray iron foundry practices. The subjects will cover every phase of foundry technique and operating practice.

Sections AMERICAN WELDING SOCIETY

CHAIRMEN, SECRETARIES AND REGULAR MEETING DATES

To Members

When in any city where sections of the Society are located—try to attend the meetings if held during your visit. This will widen your contacts in welding and enable you to interchange experience with others in similar lines of business. If no regular meeting date is given telephone the Secretary who will tell you.

ATLANTA, GA. — **1st Tues.**
CHAIRMAN—M. C. SNEAD, Link Belt Co., 1116 Murphy Avenue, S. W.
SECRETARY—R. G. WILSON, 139 Simpson St., N. W.

BIRMINGHAM — **3rd Fri.**
CHAIRMAN—E. E. MICHAELS, Chicago Bridge & Iron Co., P. O. Box 277
SECRETARY—J. E. DURSTINE, Lincoln Elec. Co., 505 No. 22nd St.

BOSTON — **3rd Fri.**
CHAIRMAN—P. J. HORGAN, General Electric Co., Lynn, Mass.
SECRETARY—P. N. RUGG, Boston Edison Co., 39 Boylston St.

CHATTANOOGA, TENN.
CHAIRMAN—E. C. CHAPMAN, Combustion Engineering Co., Hedges-Walsh-Weidner Div.
SECRETARY, CHESTER T. RAYMO, Chattanooga Boiler & Tank Company, 1011 East Main St., Chattanooga

CHICAGO — **3rd Fri.**
CHAIRMAN—TOM JONES, 8244 East End Ave.
SECRETARY—L. C. MONROE (Webster 7134), The Welding Engineer, 608 So. Dearborn Street.

CINCINNATI, OHIO
CHAIRMAN—W. W. PETRY, Cincinnati Milling Machine Co., Cincinnati
SECRETARY—J. K. ROSS, United Welding Company, Middletown, Ohio

CLEVELAND — **2nd Wed.**
CHAIRMAN—E. R. BENEDICT, Contract Welders, Inc., 2445 E. 79th Street
SECRETARY—E. T. SCOTT, Cleveland School of Welding, 2261 E. 14th St.

CONNECTICUT
CHAIRMAN—E. R. FISH, The Hartford Steam Boiler Insp. & Ins. Co., Hartford
SECRETARY—H. A. PENNINGTON, 196 Chapel Street, New Haven

DETROIT — **1st or 2nd Fri.**
CHAIRMAN—VAUGHAN REID, City Pattern Works, 1165 Harper Ave.
SECRETARY—H. P. DOUD, General Electric Company, 700 Antoinette St.

HAWAII — **4th Tues.**
CHAIRMAN—E. E. HEACOCK, Hawaiian Gas Products Ltd., P. O. Box 2454, Honolulu, T. H.
SECRETARY—R. L. MULLEN, Honolulu Iron Works Co., Honolulu, T. H.

INDIANAPOLIS,
CHAIRMAN—R. D. EAGLESFIELD, 357 S. La Salle St.
SECRETARY—I. L. WILLIAMS, P. R. Mallory & Co.

KANSAS CITY, Mo. — **3rd Mon.**
CHAIRMAN—C. E. WOODMAN, Kansas City Bridge Co., 215 Pershing Rd.
SECRETARY—ALBERT W. ROTH, 1531 Broadway

LOS ANGELES — **3rd Thurs.**
CHAIRMAN—WAYNE A. HOWARD, General Petroleum Corp., 2525 E. 37th St.
SECRETARY—J. C. GOWING, P. O. Box 186, Huntington Park, Calif.

MARYLAND — **3rd Fri. except April**
CHAIRMAN—DR. J. W. MILLER, Reid Avery Co., Ches. & Cleveland Aves., Dundalk, Md.
SECRETARY—C. N. HILBINGER, Lincoln Electric Company, Baltimore, Md.

MILWAUKEE — **2nd Wed.**
CHAIRMAN—K. L. HANSEN, Harnischfeger Corp.
SECRETARY—J. J. CHYLE, 2841 N. 51st

MONTANA — **1st Wed.**
CHAIRMAN—HENRY F. C. RUMFELT, 701 Musselshell, Fort Peck
SECRETARY—ALLEN W. BATES, Apt. 4503D, Fort Peck, Montana

NEW YORK
2nd Tues. except when Joint Meeting is held
CHAIRMAN—R. W. BOGGS, The Linde Air Products Co., 205 E. 42nd St.
SECRETARY—G. V. SLOTTMAN, Air Reduction Sales Co., 60 East 42nd Street

NORTHWEST — **3rd Wed.**
CHAIRMAN—W. E. MURPHY, Northern States Power Co., Minneapolis
SECRETARY—ALEXIS CASWELL, Manufacturers Assoc. of Minn., 405 Marquette Ave., Minneapolis

NORTHERN N. Y. — **Last Thurs.**
CHAIRMAN—W. F. HESS, Rensselaer Polytechnic Inst., Troy, N. Y.
SECRETARY—G. A. ROSS, General Electric Co., Schenectady, N. Y.

WESTERN N. Y. — **Last Mon.**
CHAIRMAN—H. J. SCHLEIDER, Air Reduction Sales, 730 Grant St., Buffalo
SECRETARY—F. O. HOWARD, Am. Steel & Wire Co., 1403 Liberty Bank Bldg., Buffalo, N. Y.

OKLAHOMA CITY — **1st Tues.**
CHAIRMAN—O. T. BARNETT, Black, Sivalls & Bryson, Inc., Box No. 1377, Okla. City, Okla.
SECRETARY—K. B. BANKS, P. O. Box 1377, Okla. City, Okla.

OMAHA, NEBRASKA
L. O. SCHNEIDERWIND, Omaha Welding Company, 1501 Jackson Street

PHILADELPHIA — **3rd Mon.**
CHAIRMAN—T. M. JACKSON, Sun Shipbuilding & D. D. Co., Chester, Pa.
SECRETARY—H. E. HOPKINS, Arcos Corp., 401 N. Broad St.

PITTSBURGH — **Middle Wed.**
CHAIRMAN—LEON C. BIBBER, Carnegie-Illinois Steel Corp., Carnegie Building.
SECRETARY—J. F. MINNOTTE, Minnotte Bros., 1201 House Bldg.

PORTLAND — **No dates set**
CHAIRMAN—G. C. DIERKING, Steel Tank & Pipe Co., P. O. Box 1899, Sta. F
SECRETARY—L. M. PICKETT, Steel Tank & Pipe Co., P. O. Box 1899, Sta. F

ROCHESTER, N. Y.
CHAIRMAN—THOS. S. GAYLORD, Eastman Kodak Co. Kodak Park Works.
SECRETARY—Paul W. James, The Lincoln Electric Co., Rochester

SAN FRANCISCO — **Last Fri.**
CHAIRMAN—N. F. WARD, University of Calif., Berkeley, Calif.
SECRETARY, J. G. BOLLINGER, Air Reduction Sales, Park & Halleck Sts., Emeryville, Calif.

ST. LOUIS — **2nd Fri.**
CHAIRMAN—A. W. HARRIS, 2449 Milk Avenue, Alton, Ill.
SECRETARY—C. W. S. SAMMELMAN, 4359 Lindell Blvd., Engineers' Club

YOUNGSTOWN (Ohio) — **2nd Mon.**
CHAIRMAN—CHARLES WATSON, Youngstown Welding & Engr. Co.
SECRETARY—C. A. WILLS, Wm. B. Pollock Co., Youngstown, Ohio

SOUTH TEXAS
CHAIRMAN—MARVIN COOK, Humble Oil & Refining Co., Houston
SECRETARY-TREAS.—MALCOLM V. REED, P. O. Box 3052, Houston

WASHINGTON, D. C. — **1st Tues.**
CHAIRMAN—A. G. BISSELL, Bureau of Construction and Repair, Navy Dept., Washington, D. C.
SECRETARY—C. A. LOOMIS, Bureau of Construction & Repair, Navy Dept., Washington, D. C.

SECTIONS BEING DEVELOPED

Note the name of the contact man in each locality who is either Chairman or Secretary of an active group interested in the formation and completion of Section Organization. Those desiring to assist should communicate with these individuals.

CANTON, OHIO (Akron, Alliance, etc.)
ROBERT M. WALLACE, The Griscom-Russell Company, Massillon, Ohio

COLORADO
J. H. JOHNSON, Johnson Supply Co., Denver, Col.

COLUMBUS, OHIO
PROF. O. D. RICKLY, Ohio State University

MIAMI VALLEY (Dayton, Troy, etc.)
E. STANSEL, Frigidaire Division, General Motors Corp., Dayton, Ohio

DALLAS-FORT WORTH, TEXAS
E. E. DILLMAN, Wyatt Metal & Boiler Works, Dallas, Texas or C. K. RICKEL Big Three Welding Equipment Co., Fort Worth

FORT WAYNE, INDIANA
JAMES MCCLURE, Wayne Welding Supply Co., 513 East Wayne St., Fort Wayne, Indiana

LOUISVILLE, KY.
A. HURTGEN, Henry Vogt Machine Company, 10th & Ormsby Streets

MEMPHIS, TENN.
B. B. DRURY, JR., Modern Engineering Company, 238 South Front St.

MOBILE, ALA.
E. D. PETIT, Air Reduction Sales Co., Canal & Water Streets

NEW ORLEANS, LA.
O. B. MCLAUGHLAN, Freeport Sulphur Co., Chairman
J. H. BULL, Lester Alexander Co., Secretary

SAN JOAQUIN VALLEY
H. S. NIX, Box 1364, Taft, Calif.

SYRACUSE-UTICA, N. Y.
JOSEPH KOGUT, Syracuse School of Welding, 1224 W. Genesee St.

TOLEDO, OHIO
J. W. SHUGARS, The Lincoln Electric Company, 632 Spitzer Building

TULSA, OKLAHOMA
R. R. THOMPSON, Air Reduction Sales Company, Tulsa, Oklahoma

WESTERN MICHIGAN
AL. G. Bond, Division St. or R. D. LAYMAN, 314 Bldg. & Loan Bldg., Grand Rapids.

WICHITA, KANSAS
R. L. TOWNSEND, Phillips & Easton Supply Co.

SECTION ACTIVITIES

ATLANTA

The January meeting of the Atlanta Section was held on the 17th in the Henry Grady Hotel. The speaker of the evening was Mr. H. C. Boardman, Director of Research of the Chicago Bridge and Iron Co., whose subject was on "Large Field Welded Tanks."

BOSTON

At the November 19th meeting of this Section, Mr. F. G. Flocke, Welding Engineer, International Nickel Company, New York, discussed the welding of monel, nickel and nickel-clad steel by gas and electric arc methods. His talk was illustrated by lantern slides.

Mr. R. F. Helmkamp, Research Engineer, Air Reduction Sales Company, presented a paper on Flame Cutting at the December 27th meeting of the Section. At this same meeting, Mr. C. T. Anderson of the General Electric Company gave an illustrated talk on "The Application of Welding to Reinforcing Frame Work for Concrete Foundations," in which he described two specific cases where welding replaced the conventional loose-wiring tied-in construction. At the conclusion of the second talk, the meeting was open for a discussion period, which lasted about one hour.

The Westinghouse Electric and Manufacturing Company is erecting an all-welded warehouse and service shop in Boston. The building is to be about 340 feet long by 180 feet wide, single story with the exception of the office, which will be on the second floor and have dimensions of 170 feet by 40 feet. The fabrication of the structural steel in this building was both shop and field welded.

CHATTANOOGA

Adoption of the A. W. S. Building Code in the pending revision of the Chattanooga Building Code is one of the first goals of the Chattanooga Section, which held its first meeting December 15, 1937.

The feature of the meeting was a talk by J. D. Gordon, of the Taylor-Winfield Corporation, Detroit, with motion pictures on "The Design and Fabrication of Welded Parts from Rolled Steel."

Chattanooga's building committee for the revision of the city building code, of which B. F. Hunt is chairman, has given the local chapter permission to work with him on the application of arc welding and gas cutting to the erection of steel buildings and the installation of pipe lines.

CHICAGO

A joint meeting with the Western Society of Engineers was held on Friday, January 21st in the 2nd Floor Auditorium of the Engineering Building. "The Application of Welding to the Heavy Construction Industries" was presented by Dr. J. C. Hodge of the Babcock and Wilcox Co. Dr. Hodge discussed the fundamentals of fusion welding as applied to heavy plate construction.

A talking motion picture was shown preceding the presentation of the paper. The picture showed views taken along the route of the China Clipper with particular reference to the use of Caterpillar tractors at air fields. A second film on "Flash Butt-Welding of Rails" was also shown.

CLEVELAND

The third meeting of the 1937–38 season of the Cleveland Section was held on Wednesday, January 12th at the Case School of Applied Science. The speaker of the evening was Mr. F. G. Flocke, Technical Service of the Development and Research Division, International Nickel Company. His subject was "The Welding of Monel, Nickel and Nickel-Clad Steel."

The Cleveland Section is sponsoring a series of six lectures in its educational course "Fundamental Metallurgy, An Outline of Metal Science for Welders," to be given by Harry B. Pulsifer, a metallurgist of the American Steel & Wire Co., in Bingham Building, Case School of Applied Science, Wednesday evenings, at 8 P.M., Feb. 2nd, 16th and 23rd, and March 2nd, 16th and 23rd. The course is for members of the AMERICAN WELDING SOCIETY.

DETROIT

The January meeting of the Detroit Section was held on the 28th in the Detroit Leland Hotel. Mr. Harold J. Sheppard, Chief Chemist, Kelsey Hayes Wheel Co., addressed the meeting on "Flame Hardening with the Oxyacetylene Flame." Mr. Sheppard's paper was accompanied by slides and a colored movie film. An additional movie film: "Modern Metal Working with the Oxyacetylene Flame," produced by the U. S. Bureau of Mines, was also shown.

Dinner at 6:30 P.M. in the Coffee Shop of the Detroit Leland preceded the meeting.

Mr. Vaughan Reid, President of the City Pattern Works, has been appointed Detroit Section Representative on the Board of Directors to fill the vacancy created by Mr. A. S. Douglass' resignation.

INDIANAPOLIS

The Indianapolis Section held a meeting on Wednesday, January 26th in the Indianapolis Athletic Club. A motion picture on the Modern Steel Factory Design and Construction was shown, which was followed by a particularly interesting address on "Welded Construction of Some Recent Industrial Buildings," by Albert S. Low, Vice-President and Chief Engineer of The Austin Company.

KANSAS CITY

The January meeting of this Section was held on the 17th in Room 501 Municipal Auditorium. The speaker of the evening was Mr. F. C. Fantz, Vice-President of the Midwest Piping and Supply Co., whose address was on "The Use of Welding in Industrial Power Plant Piping." Mr. Fantz' talk was illustrated by slides and an informal discussion followed.

The February meeting will be held on the 22nd. Mr. E. W. P. Smith of The Lincoln Electric Co., will speak on "Structural Steel Construction by Electric Arc."

MARYLAND

Mr. A. N. Kugler of the Air Reduction Sales Company, addressed the Maryland Section on January 21st, on the subject of "Multiple Pass Aircowelding." Mr. Kugler presented a very interesting address and a lively discussion followed his talk.

MILWAUKEE

The January meeting of the Milwaukee Section was held on the 12th in the City Club of Milwaukee. Mr. W. E. Swift of The American Brass Company, spoke on "Welding Copper and Copper Alloys." He discussed the physical and chemical properties of copper and its alloys, such as the various brasses, bronzes and nickel silvers.

NEW YORK

The next regular monthly meeting of the New York Section will be held on February 8th. Mr. Albert S. Low, Vice-President and Chief Engineer, The Austin Company, will address the meeting on "Welded Construction of Some Recent Industrial Buildings."

At the Executive Committee meeting of this Section held on January 13th, Dr. George V. Slottman of the Air Reduction Company, was elected to the Executive Committee and the Chairman appointed him to serve out the unexpired term of the Secretary-Treasurer of the Section.

NORTHWEST

The January meeting of the Northwest Section was held on the 27th in the Minnesota Union, University of Minnesota. Dinner preceded the regular meeting. Mr. W. B. Keelor of the Ingersoll Steel & Disc Division, Borg-Warner Corp., spoke on "Welding of Stainless and Stainless Clad Steels." Mr. Keelor covered the various welding processes and his talk was illustrated by lantern slides.

A sound film produced for the United States Steel Corp. entitled "Golden Gate Bridge" covering the construction of this monumental project was shown.

OKLAHOMA CITY

The January meeting of the Oklahoma City Section of the AMERICAN WELDING SOCIETY was held Tuesday evening, January 4th, in the Biltmore Hotel and in spite of the rather strenuous activities attending the holiday season a large number of members and friends were in attendance.

The first feature of the program was several reels of motion pictures showing the manufacture of pipe.

These films were presented through the courtesy of the National Tube Company and portrayed in a very impressive manner, the entire process from the mining of the ore to the testing and shipping of the finished products.

The various processes where illustrated not only in the manufacture of the steel itself but also the different processes used in the manufacture of the different pipes and classification of pipe in general.

The speaker of the evening was Mr. G. Raymond, Chief Engineer, of Black, Sivalls & Bryson, Inc., who spoke on the subject, "A Revolution in Joints."

The address was proceeded by numerous slides showing not only the change from riveted joints to welded joints but also the development of the welded joints through the stages of the riveted and welded joints, the lap joint, the butt strap joint and the now certainly accepted and most commonly used butt joints.

A special meeting was called for January 21st in the Biltmore Hotel in order to hear Mr. H. C. Boardman, Director of Research of the Chicago Bridge & Iron Company, present his interesting address on "Large Field Erected Tanks of Welded Construction."

PHILADELPHIA

The regular monthly meeting of the Philadelphia Section was held on Monday, January 17th in the Engineers' Club at which there were about 135 present. The subject of the meeting "Electric Welding Progress" was presented by Mr. J. F. Lincoln, President of The Lincoln Electric Company, which was followed by a lively discussion.

The following is the program for the Section up to and including May 1938.

Feb. 21st, 8:00 P.M., Engineers' Club, "The Uses of Castings in Heavy Welding Assemblies," by G. A. Jessop, S. Morgan Smith Co.

March 21st, 8:00 P.M., Engineers' Club, "Fabrication and Uses of High Yield Strength Alloys," by U. S. Steel Corporation.

April 18th, 8:00 P.M., Engineers' Club, "Welding in Modern Building Construction." Speakers to be announced.

May 1938—Inspection trip in the Philadelphia Area.

PITTSBURGH

One of the most successful and largest attended meetings of the Pittsburgh Section was held Wednesday night, January 19, 1938 in the Blue Room of the Roosevelt Hotel, at which time Mr. Charles H. Jennings, Research Engineer of the Westinghouse Electric & Manufacturing Co., presented a lecture on "European Welding Practice." The large hall was filled to capacity and some late arrivals were forced to stand.

Having just returned from a four months' tour of European countries where he investigated the welding practices of foreign companies, Mr. Jennings was able to give a very interesting and instructive comparison of the different methods he witnessed, as compared to those in use in this country. His lecture included all phases of welding, covering jobs, large and small, the various means of handling materials as practiced by others and the use of different kinds of electrodes and procedures.

It was without doubt one of the most thorough presentations of arc-welding as practiced throughout the country, ever presented before the Pittsburgh Section and many favorable comments were made by those present.

Mr. Jennings is already scheduled to present this same lecture before other sections of the AMERICAN WELDING SOCIETY and those who are fortunate enough to hear his lecture will learn many things of interest about arc-welding as it is done elsewhere.

This lecture was illustrated with slides showing specimens of work seen by Mr. Jennings, following which a general discussion was participated in by many of those present.

The next regular meeting of the Pittsburgh Section will be held February 16, 1938 in the Blue Room of the Roosevelt Hotel, this city.

Mr. Geo. F. Wolfe, Chairman of the Welding Committee, Dravo Corporation, Pittsburgh, Pa., will present a paper entitled "Assembly Plant for the Welding of Barges."

This paper covers a plant designed by the Dravo Corporation for the mass production of their standard all-welded barges—a great number of which have been built and are in use on the local rivers.

Included will be a detailed description of the preliminary operations in the structural shop and the erection of the units into their final assembly using the assembly line method. All work is completed indoors and the barge is then carried out to the launching ways and launched in accordance with standard practice.

An additional feature included in the paper (not in the original presentation at Atlantic City in September) covers the assembly of Crest Gates for the Pickwick and Guntersville Dams for the Tennessee Valley Authority.

SAN FRANCISCO

The January meeting of the San Francisco Section was postponed from the usual date of the 21st to the 28th. The principal speaker of this meeting was Mr. J. F. Lincoln, President of The Lincoln Electric Company. Mr. Lincoln's talk was both interesting and instructive.

SAN JOAQUIN VALLEY

"A Night of Metallizing" under the direction of Mr. Robert E. Kunkler, Chief Engineer, Metallizing Company of America, took place on Thursday, December 23rd in the American Legion Hall, Taft, Calif. The session was divided into two sections, the first of which was given over to the presentation of the paper on "Metallizing and Its Aid to Industry," by Mr. Kunkler; and following this, the meeting adjourned to the machine shop of the Taft Union High School where a series of demonstrations were carried on.

SOUTH TEXAS

The first regular meeting of the South Texas Section was held Thursday evening, December 16th, in the Texas State Hotel, Houston. The meeting was attended by approximately 35 persons, of which about seven were non-members. The highlight of the meeting was a paper read and interpreted by Mr. B. W. Farquhar of the Gulf Refining Company regarding the welding of Class I pressure vessels. The real action of the meeting got under way upon completion of the reading and interpretation of the paper by Mr. Farquhar in the number of rapid-fire questions asked by practically every one present, and the general discussion which followed. Later in the meeting Mr. Farquhar was called upon by the Chairman to outline some of the highlights of the recent National Convention of the Society held in Atlantic City.

ST. LOUIS

On December 10th Mr. G. O. Hoglund of the Aluminum Company of America delivered an address before the Section on the subject of "Aluminum Welding." Mr. Hoglund's paper which normally would require 40 to 50 minutes to deliver, due to the interest shown and questions asked during the course of the talk, took over two hours. After the meeting refreshments were served. An estimated attendance of over 200 were present.

On January 14th, Mr. C. E. Loos, Mechanical Engineering Department, American Bridge Company, delivered a paper on "The Use of Welding in Structural Steel." One hundred ninety three members and guests were present.

The next meeting will be on February 11th. Dr. Krivobak of the Allegheny Steel Corp. will deliver an address on the subject of "Metallurgy of Stainless Steels as Applied to Welding." The meeting will be held in the Engineers' Club Building, 4359 Lindell Boulevard, and out of town members of the A. W. S. and friends are invited.

The St. Louis Section is now arranging its program for the coming fall and winter season, namely, September 1938 to June 1939 inclusive. Suggestions for speakers on various welding subjects will be appreciated.

EMPLOYMENT SERVICE BULLETIN

A-251. Welder desires position in New York or New Jersey. Graduate of Brooklyn Engineering Institute and Kalix Welding School, also three years practical experience in shop and field work. Would consider starting as Junior Welder.

A-252. Experienced welder on alloy metals and non-ferrous metals. Will go anywhere. At present employed as sales engineer for welding rods and equipment. Can read blueprints, instruct apprentices, welding procedure control, A. S. M. E.-A. P. I. Code welder on all classes of vessels and metals. Can do lead welding. Use both arc and oxyacetylene flame. Can run a shop, solvent business, and meet the public.

A PRECISION PRODUCT FOR AN EXACTING USE

McKay

OFFERS YOU A NEW SOURCE FOR SUPERIOR SHIELDED-ARC WELDING Electrodes

McKAY SHIELDED ARC WELDING Electrodes

A concern with fifty-odd years of honorable service to industry behind it—a manufacturing policy which has made McKay chains and other McKay products recognized everywhere as standard in their respective fields—a plant as highly modern and definitely specialized as any in the world—a corps of technicians and scientists of the highest standing—such a source guarantees to every user of McKay Electrodes a welding rod worthy of his confidence. There are types and sizes for all requirements. On special welding problems the McKay engineers invite correspondence. Learn about McKay Electrodes. Folder mailed on request.

THE McKAY COMPANY

McKAY BUILDING PITTSBURGH, PA.

THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

Sponsored by the American Welding Society and American Institute of Electrical Engineers

Supplement to the Journal of the American Welding Society, February 1938

WELDING RESEARCH PROBLEMS

Compiled by the Fundamental Research Division of the Welding Research Committee of Engineering Foundation

Purpose: To Stimulate Fundamental Research in the Universities

TABLE OF CONTENTS

	Page
Welding Research	1
Value of Research to the University	2
The Fundamental Research Division	2
List of Publications	5
List of Fundamental Research Problems in Welding	5
SUGGESTED RESEARCH PROBLEMS	6
Shrinkage Stresses in Welding, by *Professor R. E. Jamieson*	6
Welding of Copper and Its Alloys, by *Professor A. S. Young* (discussion by *I. T. Hook* and *D. K. Crampton*)	7
Effect of Carbon and Manganese in the Welding of Steel, by *R. H. Aborn*	7
Welding Cast Iron, by *Professor W. A. Spindler*	8
Impact Tests of Welds, by *Professor O. H. Henry* (discussion by *M. F. Sayre, C. E. Loos, A. B. Kinzel, I. T. Hook* and *H. V. B. Madsen*)	9
OTHER SUGGESTED RESEARCH PROBLEMS	12
First Steps in Welding Research	15
Bibliographies (References to 1937 Welding Literature)	15
I. Resistance Welding	16
II. Welding Non-Ferrous Metals (Other Than Copper and Aluminum)	20
III. Aluminum Welding	21
IV. Welding Copper and Its Alloys	25
V. Flame Cutting	26
VI. Arc Phenomena	28
VII. Gas Welding	30
VIII. Non-Destructive Tests for Welds	32
IX. Hard Facing and Flame Heat Treatment	34
X. Arc Welding Generators and Transformers	35

WELDING RESEARCH

The distinguishing thing about progress in welding, as in any other branch of engineering, is that we can always do much more with a given phenomenon, process or material after we have found out as much as we can about its nature. The primary discoveries in welding have been made very largely by men who had a broad grasp of all the scientific knowledge available in their time, and had the facilities to apply that knowledge. They applied the systematic principles of fundamental research, relying on cut-and-try methods only to the extent that their information was deficient. It is the principle of fundamental research to which the members of our Division are committed as a body in their search for new knowledge in welding.

RECENT advances in welding as a standard method of joining metal parts in manufacturing, construction, production and maintenance work have been almost phenomenal. As is true of arts of this sort, the practical applications tend to outstrip the applier's knowledge of the underlying sciences.

Failures and difficulties are, therefore, bound to occur in any new application or extension of the process. Today it is not unusual for industrial companies to spend several thousands of dollars, often $10,000 to $20,000, to overcome some particular difficulty. The same work may be duplicated to a considerable extent by competitors, or by others in allied industries. Moreover, such investigations are usually carried through only far enough to solve the immediate problem. Very often additional investigations of 20% or 25% the total cost could supply basic information for a thorough understanding of the phenomena involved. With this information at hand, kindred problems can be solved with little additional cost, and with far greater assurance as to correctness of final results.

It also happens that a great many preliminary investigations are extremely wasteful, and could be avoided if one had at hand in usable form a complete picture of existing knowledge on the subject which is available in the literature throughout the world.

The most rapid advances in welding have been made

during the last decade. The frontiers of knowledge of the subject are being extended daily. The need for trained young men familiar with the fundamental principles, and having a thorough knowledge of the metallurgy involved is constantly growing.

Welding may be viewed from a large number of research angles. In the first place, there are the sources of welding heat: arcs, flames, sparks, electric resistance, induced currents, chemical (thermit) and electrolytic reactions and combinations thereof. Each of these has a scientific history, and each possesses a lively scientific interest at the present time.

Secondly, there are the metals used in welding. Practically all metals and alloys can be welded, bronze welded or soldered. From Al to Zn, from tin (melting point 232° C.) to tungsten (melting point 3400° C.), all may be welded singly or in combinations. The metallurgical factors encountered in welding any one of these metals range from the physical chemistry of melt and slag reactions, through the technology of casting, to the entire problem of the effects of all ranges of temperature on the base metal from the standpoints of structure as well as of strength, elasticity and residual stresses.

Then there are the applications of welding in engineering construction. Problems arise here for the structural and testing engineers—for the former in the evolution of designs utilizing all the possible but still unrealized advantages of welded construction—for the latter in determining what properties are actually inherent in welded construction.

Finally, there are the widespread applications of welding principles, equipment and methods in such processes as flame heat treatment, hard surfacing, flame cutting and metal spraying.

VALUE OF RESEARCH TO THE UNIVERSITY

There are few who will gainsay the value of research, whether in welding or in other fields. The value of research to the teacher and student has been admirably outlined by Professor W. M. Wilson. "Advanced students should participate in creative thought, and the research work should be genuine. Simulating research by solving problems that have already been solved by others may develop technique and may be intensely interesting. Moreover, it may develop a love of knowledge. But such work should be supplemented by genuine research, the solution of problems, however small, to which neither the teacher nor any one else knows the answer. Otherwise, the spirit of intellectual adventure will be lacking. The student must experience the groping, the failures, the continued effort without apparent success, the receptive attitude of the conscious mind for suggestive glimpses from the subconscious mind, the alertness for significant phenomena, the consuming interest that will make continuation of the work more important than eating or sleeping and finally, he must experience the exhilaration of success. All of these go into the training of a creative thinker. For the first time he will experience the satisfaction of collecting facts and arranging data so that their logical organization leads to a definite conclusion independent of any contribution from any one except himself and his teacher. It is a new experience in his intellectual life, and it enlarges his conception of his possibilities.

"Developing creative thinking is expensive teaching, partly because the number of creative thinkers among teachers is small so that their salaries are likely t greater than that of the average teacher, partly be the ratio of students to teacher is likewise small fo type of teaching, and partly because, to retain his p ciency, the teacher must continue his research work

Research also forms one of the most important l between engineering schools and industry. As Dr. K T. Compton pointed out in a recent address: "No ma an engineering school is likely to make a direct contri tion to an industrial art unless he is in some way direct associated with the problems of industry."

In a recent address Dr. Frank B. Jewett said, "Ear in my career as one of his assistants, General J. J. Car impressed on me the importance of getting facts before forming opinions or drawing conclusions if one wished to obtain a valid and acceptable answer. It was his belief, and one he operated on consistently, that the answer to almost any question was 90 per cent automatically self-evident if one took the trouble to assemble and scrutinize the known or ascertainable facts which bore on it. Any one who was ever involved with him in consideration on some knotty problem will never forget the interminable hours, days and even weeks or months which he devoted to fact-finding. It was soul and patience-trying and it led into most unexpected places and to most unexpected individuals but it got results that were rarely wrong."

THE FUNDAMENTAL RESEARCH DIVISION

There are two main purposes of the Fundamental Research Division. These are: (1) to interest the colleges of this country in problems which relate to welding in order to familiarize the professors and students of these universities with this growing and important tool; and (2) to bring to bear upon fundamental problems needing solution the scientific minds which are free from commercialism and from the necessity of producing results of immediate commercial value. In other words, the university atmosphere should be most conducive to pursuing research until the truth is disclosed as compared with discontinuing it as soon as just enough data have been obtained to serve the immediate commercial objective. As Professor Adams has stated many times, "If we could only learn the fundamental truths underlying a certain phenomenon, the reason why of things, we could with very little additional investigation apply this knowledge to the solution of dozens of practical problems, and with greater degree of certainty as to the correctness of these solutions." Both these purposes have been successfully accomplished. We now have more than 40 professors actively engaged in various problems, and the reports which result from their research work each year form the basis for a considerable number of important papers which are usually presented at the annual meeting of the AMERICAN WELDING SOCIETY.

Probably no other organization in the engineering world operates with less organization and with greater opportunism. The underlying motif has been to interest each professor in some problem, and to assist in every way possible in the furtherance of such research work as he may undertake.

For the past four or five years a conference has been held annually, usually at the time of the annual meeting of the AMERICAN WELDING SOCIETY, and the railroad and pullman expenses of attending professors have been de-

Lately, because of limitation of funds, it has been ry to limit the amount appropriated to any one ual to $50. At this conference the research s meet with one another and compare their re- experiences, and, through correspondence, are to each other after returning to their respective tories. The conference also enables them to make intances with many people in the welding industry. order to assist still further in mutual cooperation, groups have been organized in several industrial ers with the idea that such groups will serve as an piration to other universities in the vicinity, and ply the needs of the professors in the particular lity.

It is not at all surprising that these groups have operated with varied success, most of them in entirely different ways; and the good accomplished has in nearly every instance been of an opportunistic nature.

MEMBERSHIP OF THE FUNDAMENTAL RESEARCH DIVISION

The following membership list and list of publications issued by the Division during the past year provide some idea of the Division's activities.

FUNDAMENTAL RESEARCH DIVISION

Alphabetical List of Researchers, Their Affiliations and Their Subjects. (As Revised January 1938)

Research Being Conducted by	Subject of Research
1. Prof. Edward Bennett Univ. of Wisconsin	Studies Relating to the Selective Heating of Large Conducting Bodies in Strips by Utilizing the "Proximity Effect" to Control the Distribution of Heating Currents of the Audio Frequency Range
2. Prof. H. Beresford Univ. of Idaho, Agricultural Engg. Dept.	Application of Wear Resistant Surfaces to Agricultural Equipment and Tools
3. Prof. H. M. Boylston Case School of Applied Science, Dept. of Metallurgy	(*a*) Metallurgical Investigations on Welds (*b*) Factors Influencing the Welding Quality of Steel
4. H. R. Bullock Massachusetts Institute of Technology	Study of Oxyacetylene Cutting
5. Prof. H. L. Daasch Iowa State College, Dept. of Mech. Engg.	Flame Cutting
6. Prof. R. P. Davis West Virginia Univ.	Inactive at Present
7. Prof. A. V. deForest Massachusetts Institute of Technology, Mech. Engg. Dept.	Vibration Studies of Welded Structures
8. Prof. D. J. Demorest Ohio State Univ.	Coatings for Welding Rods
9. Prof. J. P. DenHartog Harvard Univ.	Influence of the Welding Heat on the Structure of the Adjacent Metal
10. Prof. G. E. Doan Lehigh Univ., Dept. of Physical Metallurgy	(*a*) Causes and Conditions of Crater Formation in Arc Welding (*b*) A Study of the Basic Nature of the Arc Discharge Under Conditions of High Purity (*c*) The Properties of Weld Metal Made with Pure Iron in Argon and Other Atmospheres (*d*) The Use of Gamma Rays for Weld Examination (*e*) Acceleration of Rate of Welding by Additions to the Welding Wire
11. Dr. F. C. Fair New York Univ., Dept. of Chemical Engg.	Metallography of Alloy Steel Welds
12. Prof. S. L. Goodale Univ. of Pittsburgh, Dept. of Metallurgy	(*a*) Annealing of Welded Joints (*b*) Strain Annealing of Medium Carbon Steel (0.25 to 0.30%)
13. Prof. S. H. Graf Oregon State Agricultural College	(*a*) X-Ray Diffraction Studies on Stresses in Welds (*b*) Heat Effects in Weld Metal
14. Prof. P. R. Hall Pennsylvania State College, Dept. of Industrial Engg.	Welding of Cast Iron
15. Prof. O. H. Henry Polytechnic Institute of Brooklyn, Dept. of Mech. Engg.	(*a*) Effect of Low Temperature on the Static and Dynamic Tensile Strength of Welded Joints in Some Ferrous and Nonferrous Metals (*b*) Fatigue Tests of Welded Joints at Low Temperatures
16. Prof. W. F. Hess Rensselaer Polytechnic Institute, Dept. of Metallurgy	(*a*) Ignition of Alternating Current Arcs (*b*) Impact Studies of Fillet Welds (*c*) Resistance Welding
17. Prof. N. S. Hibshman Lehigh Univ.	Inactive at present
18. Prof. S. C. Hollister Cornell Univ.	(*a*) Locked-Up Stresses in Welds (*b*) Repeated Stress in Welded Connections
19. Prof. T. P. Hughes Univ. of Minnesota, Dept. of Mech. Engg.	(*a*) Relation of Current and Voltage to Speed of Welding (*b*) Ductility Values as Obtained by the Tensile and Cold-Bend Tests

20.	Prof. M. A. Hunter Rensselaer Polytechnic Institute	
21.	Prof. R. E. Jamieson McGill Univ. Montreal, Dept. of Civil Engg.	Initial Stress Caused by Welding
22.	C. H. Jennings Westinghouse E. & M. Co., Pittsburgh	Strength and Design of Welded Joints
23.	C. D. Jensen Lehigh Univ., Civil Engg. Dept.	(*a*) Welded Girders with Inclined Stiffeners (*b*) Stress Distribution in Fillet Welds Subjected to Bending
24.	W. C. Johnson Princeton Univ., Dept. of Electrical Engineering	Spot Welding
25.	Prof. W. B. Kouwenhoven Johns Hopkins Univ.	(*a*) Flux Penetration Tests (*b*) Non-Destructive Tests for Welds
26.	Prof. W. J. Krefeld Columbia Univ., Dept. of Civil Engg.	Welded Beam Connections
27.	Prof. T. R. Lawson Rensselaer Polytechnic Institute, Head, Dept. Civil Engg.	(*a*) Quantitative Studies of the Stresses Caused by Welding Operations (*b*) Photoelastic Studies of Stresses in Riveted and in Welded Joints (*c*) Impact Stresses in Welded Joints
28.	Dr. H. H. Lester Watertown Arsenal	X-Ray Specifications for Castings and Welded Structures
29.	Prof. Inge Lyse Lehigh Univ., Fritz Engg. Lab.	(*a*) Welded Reinforcing Bars (*b*) Rigidity of Welded Structural Connection (*c*) All-Welded Vierendeel Trusses
30.	Dr. D. W. Murphy Univ. Michigan, Dept. of Engg. Research	Determination of Oxygen and Nitrogen Content
31.	Dean J. A. Needy Ohio Northern Univ., College of Engg.	Problems in the Welding of Cast Iron
32.	Prof. J. T. Norton Massachusetts Institute of Technology, Dept. of Mining & Metallurgy	(*a*) Radiographic Technique of Examining Welds (*b*) X-Ray Diffraction Method for Investigating Stresses in Welds (*c*) X-Ray Studies of Age-Hardening
33.	F. A. Rappolt College of the City of New York	Welded Beam Connections
34.	Prof. O. D. Rickly Ohio State Univ., Dept. of Industrial Engg.	(*a*) Study of Residual Stresses in Welded Joints (*b*) Shear and Impact Tests of Welds
35.	Prof. M. F. Sayre Union College, Dept. of Civil Engg.	(*a*) Development of Methods of Testing Welds (*b*) Study of Cracks in Welds
36.	Prof. G. S. Schaller Univ. Washington, Dept. of Mech. Engg.	(*a*) Development of an Arc with a Gaseous Atmosphere (*b*) Oxyacetylene Welding of Cast Iron
37.	Prof. R. R. Seeber and A. P. Young Michigan College of Mining and Technology, Dept. of Mech. Engg.	(*a*) Copper Welding (*b*) Method of Testing Welds
38.	Prof. A. H. Sluss and V. M. Smith Univ. of Kansas	Fatigue Testing of Fusion Welded Butt Joints
39.	A. Solakian Columbia Univ.	Photoelastic Studies
40.	Prof. W. A. Spindler Univ. of Michigan, Dept. of Metal Processing	Welding Cast Iron
41.	Prof. J. G. Tarboux Univ. of Tennessee	Magnetic Field Intensities Surrounding Arcs
42.	Dr. E. Therkelsen and G. J. Pesman Montana State College, Dept. of Mech. Engg.	Distortion of Welded Pipe Structures
43.	Prof. F. H. Rhodes and R. David Thomas, Jr. Cornell Univ., Dept. of Chemistry.	Chemical and Metallurgical Reactions in the Electric Arc
44.	Prof. G. E. Thornton State College of Washington, Dept. of Mech. Engg.	Fatigue Tests
45.	Dr. A. E. Vivell Princeton Univ., Dept. of Electrical Engg.	Non-Destructive Testing
46.	Prof. N. F. Ward Univ. California, Dept. of Mech. Engg.	(*a*) Creep Tests of Arc Welds in Steel (*b*) Heat Transfer in Resistance Welding
47.	W. L. Warner Watertown Arsenal	(*a*) Heat Effect of Arc Welding on Various Alloy Steels (*b*) Effect of Preheating on Weldability of These Steels
48.	Prof. A. E White Univ. of Michigan	(*a*) Creep of Metals and Welded Structures at High Temperatures (*b*) Resistance to Oxidation, Embrittlement and Fatigue (*c*) Stresses in Annealed and Unannealed Welded Pipe
49	Prof. W. M. Wilson Univ. of Illinois, Dept. of Civil Engg.	Fatigue Tests of Large Welded Specimens

50. S. F. Yasines
New York Univ., Dept. of Civil Engg. — Notch-Impact Tests of Welds in Low-Alloy Steel

51. Dr. M. Yatsevitch
Watertown Arsenal — Coefficient of Expansion of Weld Metal

It will be seen that the membership of the Fundamental Research Division comprises professors interested in the conduct of fundamental welding research as well as representative scientists in industry.

Local Committees.—To expedite progress and to hold more frequent meetings of local groups interested in fundamental welding research as well as to promote more active cooperation of local industries, branches of the Fundamental Research Division have been formed in:

New York—*Chairman:* O. H. Henry, Polytechnic Institute of Brooklyn.
Pittsburgh—*Chairman:* C. H. Jennings, Westinghouse Electric & Manufacturing Company.
Pacific Southwest—*Chairman:* N. F. Ward, University of California.

It is desirable to endeavor to obtain the advantages of decentralization by establishing local sub-divisions. Their success depends to a large extent upon the activity of the Chairman appointed. Sometimes the appointee, while at first active, finds that other duties gradually interfere. In such cases, the Chairmanship automatically lapses and is again established when a new and active volunteer can be secured.

The philosophy of operation of these local groups has been explained above. It seems, however, that a concerted effort should be made on the part of the central office and the individual professors to cooperate locally either with a company or laboratory, or groups of companies, *or with the local sections of the* AMERICAN WELDING SOCIETY in order that the needs of each professor may be promptly taken care of without the routine of going through the central office. The more these operations become decentralized, the greater will be the progress. The central office feature of our plan of organization is well adapted to fitting varied needs and preferences. Any group can be autonomous to whatever extent it prefers, when it believes that the central office can be of assistance, it should apply. The central office maintains a qualified staff ready to assist in all ways possible.

LIST OF PUBLICATIONS

During the year the following reports were published by members of the Committee:

Welded Beam-Column Connections—I. Lyse and G. J. Gibson, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1936, pp. 34–40.
The Effect of Low Temperature on the Tensile Impact Resistance of Iron, Steel and Welded Joints—O. H. Henry, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1936, Supplement, pp. 2–9.
Welded Structural Brackets—C. D. Jensen, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1936, Supplement, pp. 9–15.
Electric Heating by the Proximity Effect—Edward Bennett, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1936, pp. 16–20.
Characteristics of a Universal Welding Generator—N. F. Ward, AMERICAN WELDING SOCIETY JOURNAL, Nov. 1936, pp. 2–7.
A List of Fundamental Research Problems, AMERICAN WELDING SOCIETY JOURNAL, Nov. 1936, Supplement pp. 1–40.
Micro Testing Machine, Chevenard, tr. by M. Scioletich, AMERICAN WELDING SOCIETY JOURNAL, March 1936, pp. 11–13.
Progress in Welding During Last Six Months of 1936—W. Lohmann, AMERICAN WELDING SOCIETY JOURNAL, June 1937, Supplement, pp. 11–16.
Strain Measurements in Welded Joints—J. L. Banville and H. A. Storrs, AMERICAN WELDING SOCIETY JOURNAL, June 1937, Supplement, pp. 1–4.
An Investigation of Plug and Slot Welds—G. J. Gibson, AMERICAN WELDING SOCIETY JOURNAL, July 1937, Supplement, pp. 10–21.
Peening and Its Effects on Arc Welds—E. M. MacCutcheon, Jr., and D. M. Kingsley, Jr., AMERICAN WELDING SOCIETY JOURNAL, July 1937, Supplement, pp. 22–28.
Welded Girders with Inclined Stiffeners—C. D. Jensen and W. F. Lotz, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 27–29.
Welding of Copper—A. P. Young, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 30–40.
Static and Impact Tensile Properties of Stainless Steel Welds at Ordinary and Low Temperatures—O. H. Henry, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 41–46.
Effect of Welded Top Angles on Beam-Column Connections—Inge Lyse and G. J. Gibson, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 2–9.
An Alternating Current Non-Destructive Test for Welded Seams—W. B. Kouwenhoven and A. E. Vivell, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 47–50.
X-ray Methods of Studying Stress Relief in Welds—J. T. Norton, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 19–22.
Fatigue Tests of Butt Welds in Structural Plates—W. M. Wilson, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 23–27.
Studies of the Oxyacetylene Cutting Process—H. R. Bullock, AMERICAN WELDING SOCIETY JOURNAL, Oct. 1937, Supplement, pp. 50–52

LIST OF FUNDAMENTAL RESEARCH PROBLEMS IN WELDING

First prepared in 1932 the list of fundamental research problems issued by the Fundamental Research Division has been revised on several occasions to keep abreast of innovations and developments. Nevertheless, some of the problems which appeared in the original list will be found in this year's list.

The revised list is based to a large extent on the reviews of welding literature that have appeared in the Research Supplement from time to time during the past year or two. Since these reviews show what *is* known about a given topic, several members of the Division have prepared lists of what *is not* known about the subjects of the reviews. In two cases the lists are accompanied by discussions. In each instance these reviews reflect the opinion of the authors rather than the Fundamental Research Division.

Suggested Research Problems

SHRINKAGE STRESSES IN WELDING

By PROFESSOR R. E. JAMIESON†

The attack on the problems of shrinkage stresses should have, among others, two important objectives. We must determine the extent to which these stresses are responsible for local failures, such as cracks, occurring before the work receives its load, and we must obtain the relation, if any, between the shrinkage stress system and the structural behavior of the finished part under applied external load. A great deal of work has been done on the determination of shrinkage stresses in various types of specimen, and several methods have been devised for the purpose. The results obtained vary widely, but there is ample evidence of the presence of elastic stresses of a high order remaining in the welded work after it has cooled to room temperature.

It is, however, not sufficient to know that such stresses exist in the finished work. We must also know their effect on its behavior in service, so that due allowance may, if necessary, be made in the design. The numerical values of shrinkage stress reported by various investigators have in some cases been startling, but nevertheless welding continues to produce very satisfactory and serviceable results, and it is at least doubtful whether shrinkage stresses as such are responsible for all, or even a large part, of the troubles that are laid to their influence. It may be that in some cases the shrinkage stresses are highly localized, and of only partial effect in the direction of future applied working stresses, and of the same order of significance as the residual stresses due to rolling present in the parent metal.

The X-ray diffraction method for the investigation of strains, developed by Professor Norton, should prove very valuable in the attack on the relation between shrinkage stresses and local failures. This method enables comparisons to be made of strain conditions in very small areas on the surface of a specimen. It would be interesting to obtain a series of readings by this method, covering a section of a plate which is known to be in a condition of varying complex stress, as, for example, a plate to one or both edges of which a weld bead has been applied.

For the second objective mentioned, the relation between shrinkage stresses and structural behavior, measurement of the stresses should be accompanied in each case by an investigation of the behavior of corresponding specimens under external loads simulating working conditions, and including both static and fatigue tests. A sufficient number of identical specimens would be required in each series to provide one specimen for stress determination and one for each loading test. The subdivision method of stress measurement appears to offer the greatest promise in this case.

† McGill University.

Suggested problems are:

1. Magnitude and distribution of shrinkage and reaction stresses in spot and seam welded assemblies, and of shrinkage stresses in flash welds and resistance butt welds.
2. Shrinkage stresses in welded high-alloy steels.
3. Shrinkage stresses in welded non-ferrous metals. Do shrinkage stresses (if any) in welds in some non-ferrous metals which exhibit a measurable creep rate at room temperature disappear in the course of time? What relief or increase of shrinkage stresses may be expected by aging reactions at room temperature in some precipitation hardening non-ferrous alloys. (An annotated bibliography of articles dealing with the residual stresses set up in metals by aging or allotropic transformations is available upon request to the Secretary.)
4. Magnitude and distribution of shrinkage stresses perpendicular to the surface of the plate (in the direction of the thickness) in welds in plate more than about ½ inch thick. Probably the X-ray diffraction method of Professor Norton could be adapted to this problem.
5. Shrinkage stresses in arc welds made in thick plates in a single pass.
6. Shrinkage stresses in soldered, bronze-welded and thermit-welded joints.
7. Effect of shrinkage stresses (if any) on the buckling of welded rails.
8. For a given type of weld in a given material is there a relation between heat input, speed of welding (arc, gas, flash, etc.), speed of cooling (Newton's Law) and shrinkage stresses perpendicular to the weld? A quantitative theory of this sort based on combined plastic and elastic deformation has been evolved by Boulton and Lance Martin (*Trans. N.E. Coast Instn. Engrs. Shipbuilding*, 53, 255–281 (1937)) for shrinkage stresses parallel to the weld at all times before and after the source of welding heat has passed a given section.
9. A complete and analytical catalogue of welding cracks with accompanying quantitative data on the rate and temperature of propagation of the crack, and the magnitude of the shrinkage stresses.
10. There is a need for a review of theoretical and experimental work on multi-axial stresses. It is believed that a cause of brittle cracks at room temperature in ductile welds is multi-axial stress, but it is not known to what extent multi-axial stresses may be expected to reduce the capacity for deformation (slide) and to account for brittle failure. (An annotated bibliography on some phases of theories of strength is available upon request to the Secretary.)
11. Thermal shock tests (plunging a locally heated body into a quenching bath) as an indication of the response of a metal to some of the factors involved in weldability without introducing the complications of weld metal or extensive microstructural changes.
12. To what extent may overstrain be relied upon to relieve shrinkage stresses in welded higher carbon steel? To what extent does impact overstrain relieve shrinkage stresses in welded low-carbon steel?
13. There is a large amount of information on relief of external stress on unwelded metal by stress annealing. To what extent does it apply to the relief of different systems of shrinkage stresses in welds by annealing? Are the reservations important or minor? (An annotated bibliography on the effect of annealing on relief of stress in unwelded metals is available upon request to the Secretary.)
14. A table containing reliable quantitative data on the physical properties (thermal and electric conductivity, vapor pressure, yield strength, etc.) of metals at all temperatures that are important for all types of welding.

WELDING OF COPPER AND ITS ALLOYS

By PROFESSOR A. P. YOUNG

Based on the Review of Literature by I. T. Hook, entitled The Welding of Copper and Its Alloys, AMERICAN WELDING SOCIETY JOURNAL, Feb. 1937 Supplement, pp. 7–31; March 1937 Supplement, pp 33–46

NOTE: Mr. Hook's discussion of the problems has been inserted in parentheses after the problem concerned. Dr. Crampton's comments have also been inserted as notes.

1. Effect of small additions of other elements on the welding properties of copper.

(*a*) Aluminum, its advantages and disadvantages in small percentages for gas welding. (Aluminum has such an adverse effect on the welding (lowers the bond strength to steel) properties of the yellow, high-zinc welding bronzes, that little has been done with it as a deoxidizer for copper.)

(*b*) Silicon, its effects on the resistance and spot welding of copper sheet. (Desirable to obtain a graph showing effect of increasing percentages of silicon in copper on the resistance, strength, ductility, etc.)

(*c*) Lithium, barium and boron as deoxidizers of copper for welding. (Desirable to measure effect of lithium, barium, strontium and boron as deoxidizers for copper.)

(*d*) Cadmium as an addition to a welding rod for copper, and its effectiveness compared with phosphorus.

(*e*) Developing effective substitutes for phosphorus as deoxidizer in the welding of copper. There has been doubt expressed, in view of the rather low heat of formation of P_2O_5 and of the very high vapor pressure of phosphorus and P_2O_5, whether the effect of phosphorus in welding brass is a deoxidizing effect or simply a blanketing effect preventing access of undesirable gases to the weld. The behavior of zinc in the presence of phosphorus as sole deoxidizer also seems worthy of investigation. Desirable to find another deoxidizer which will have less effect on the electrical conductivity and ductility of the copper.)

2. Effect of a third element on the welding of alloys.

(*a*) Cobalt as a third element in the welding of copper alloys.

3. A study of fluxes, their function, optimum composition, method of application and results.

4. Effect of fluxes on the welding of copper-zinc alloys, and a study of the preparation of brass plates for welding and brazing. (A study of the fundamental functions of the flux is very desirable, i.e. how much of a given oxide can a given flux dissolve at the welding temperature? How much coverage does a given flux provide at a given temperature, etc.?)

5. The effect of nickel as a third element in welding rods for thick and thin plates, and the possibility of employing a third element as a deoxidizer.

6. Development of a satisfactory flux–coated cupro–nickel welding rod.

7. The relative effectiveness of copper deoxidizers in the different welding processes.

8. Effect of remelting of eutectic areas in welding copper castings. (An important consideration would be the type of atmosphere accompanying the melting heat—in particular the atmosphere of an oxyacetylene torch, the carbon arc, atomic hydrogen torch.)

9. Study of resistance spot, seam and projection welding of copper to establish limits of thickness of sheets. (Resistance spot welding of copper is not regarded as important but any work on copper alloys having a conductivity International Annealed Copper Standard of 30% or less is very desirable.)

10. Further research on the atomic hydrogen welding of copper.

11. Development of a satisfactory alloy and procedure for welding copper by the metallic arc process. (Not especially important as the carbon arc functions very well. Desirable to evaluate the coated German rod invented by W. Lessel (The Welding Industry (London) March & April 1937).)

12. Further study of the metallic arc welding of silicon copper, development of a flux coating and methods for increasing ductility after welding. (Opinion is divided on the desirability of this research.)

13. Research on the weldability of the following alloys: copper-cadmium, copper-aluminum and copper-beryllium. What percentages of alloying element should be present in plate and rod for best welding results?

Problems suggested by Mr. Hook are:

14. Means of transferring the skill of the best workmen to the automatic welding machine.

15. The resistance butt welding of hot-short copper alloys.

16. The flash welding of copper alloys having a large range of temperature between liquidus and solidus. (14, 15 and 16, apply to resistance spot, seam and butt welding.)

17. An analysis of the factors involved in torsion testing spot welds in copper alloys. (Very desirable.)

Other problems suggested are:

18. The variation with temperature of the mechanical properties of copper alloy for spot welding electrodes. What mechanical properties are critical? (Compression strength is a most critical property at various temperatures. Tendency to alloy with base metal is a most important metallurgical property.)

19. Detection of excessive internal stresses in welded brass by means of the mercurous nitrate test. (Not a very good test for this purpose.)

20. Recovery of deoxidizing elements in welding copper and its alloys. (It is very desirable to know how much deoxidizer is lost in various welds.)

EFFECT OF CARBON AND MANGANESE IN THE WELDING OF STEEL

By R. H. ABORN†

These suggestions although having no direct connection with the welding of carbon-manganese steels, do have a very important bearing on the factors which influence weldability and the suitability of welded products. The first suggestion and possibly the most important is the determination of critical cooling rates of a series of carbon-manganese steels by the Bureau of Standards method described in T. G. Digges' paper on "Effect of Carbon on the Hardenability of High Purity Iron Carbon Alloys" before the 1937 A. S. M. Convention. These would serve to show the influence of manganese on the tendency to form martensite as the cooling rate is increased with vary-

†U. S. Steel Corp.

ing amounts of carbon. These critical cooling rates could then be related to cooling rates in actual welds.

The second problem is the determination of tensile properties of carbon-manganese steels at elevated temperatures. Although the statement is made in the recent literature survey (AMERICAN WELDING SOCIETY JOURNAL, Sept. 1937, Supplement, pp. 23–32.) that the high temperature strength parallels the room temperature strength, it is not at all certain that this will be found to be the case when systematic studies of both long-time and short-time loading tests are made.

A third problem is the more systematic study of the influence of carbon and manganese contents on the austenite grain coarsening characteristics.

In all of the above tests it is important that the steels used be made by similar melting and deoxidation practice and subsequently the same properties could well be investigated on steels made by different practices, such as open steel, silicon-killed steel and aluminum-killed steel.

WELDING CAST IRON

By PROFESSOR W. A. SPINDLER†

The following problems are some of those on which further work is needed as indicated in the Review of the Literature on the Welding of Cast Iron, appearing in the Research Supplement of the March 1937 issue of the AMERICAN WELDING SOCIETY JOURNAL.

1. Cause of Hard Spots.—It is generally considered that difficulties, including hard zones, arise in the welding of carbon steels when the carbon content exceeds about 0.3 per cent. In cast iron with a total carbon content usually above 2.5 per cent the difficulties of controlling weld hardness and other properties are intensified and not completely understood. While hard spots are usually considered as decreasing machinability, their adverse effect on weld strength and other properties is also important and should be studied.

In the above cited review of the literature, twelve causes of hard spots are listed on which further clarifying research is needed. Undoubtedly some of these causes are more important than others and further study should be made to establish the types of irons and welding conditions and procedure where each cause becomes active. One of the more important causes of hard spots is the rate of cooling which with associated temperature distribution and shrinkage stresses are considered in the two following sections.

2. Rate of Cooling and Preheating.—It appears that the primary effect of preheating is to reduce the rate of cooling although the more uniform temperature distribution due to preheating results in lower shrinkage stresses. It is known that the hard, unmachinable and brittle white iron and martensitic structures result from very rapid cooling rates. Yet there is no quantitative information available on cooling rates of welds, due no doubt to the difficulties of measurement involved. The rates of cooling through the temperature ranges where graphitization and phase changes occur are especially significant and should be fully studied. A method of measuring cooling rates is discussed in a recent Review of the Literature on Temperature Distribution During Welding (AMERICAN WELDING SOCIETY JOURNAL, Sept. 1937, Supplement, pp. 4–10).

3. Shrinkage Stresses and Their Effect on Weld Properties.—Cast irons generally, being comparatively non-ductile alloys, are especially sensitive to cracks in the weld or heat-affected zone due to severe temperature gradients and resulting high shrinkage stresses. These microscopic cracks in conjunction with hard spots and high residual stress may account for low physical properties obtained in many welds in cast iron.

Methods for measuring residual stresses are contained in a recent Review of the Literature on Shrinkage Stresses in Welding (AMERICAN WELDING SOCIETY JOURNAL, Nov. 1937, Supplement, pp. 2–62). Studies of stresses should include consideration of all factors which affect temperature gradients, including preheat, rates of heating and welding procedure. Subsequent heat treatment and strengths of alloys at heat treating temperatures are also factors in this work.

4. Effect of Variations in the Composition of Cast Iron on Its Weldability.—Further studies should be made on the effect of variations of the usual chemical elements as well as additions of special elements to the base metal and filler metal. Improvement in ease of welding including reduced preheat and increased welding speeds should result from these studies as well as better and more uniform weld properties. Representative alloy and high-strength irons should be included in these researches.

5. Compositions of Fluxes, Electrode Coatings and Slags.—Little appears to be known about the composition of slags produced in the welding of cast iron. Likewise there is much difference of opinion as to flux compositions and the resulting effect on ease of welding and weld properties. Electrode coatings are used to add certain desirable chemical elements to the weld metal as well as act as a flux and should be fully studied. Extensive and tedious chemical analyses are needed to correlate weld chemistry with metallographic and physical properties of the welds and deposited metal.

6. Gas Holes and Porosity.—Considerable disagreement and inconclusive experimental evidence is found in the literature as to the cause of porosity in cast-iron welds. Thermodynamic and physical chemical studies as well as experimental attack should forward solution of this problem. The effect of fluxes and coatings in deoxidizing and degasifying the deposited metal should be studied as well as the variables of welding procedure.

7. Comprehensive Studies of Physical Properties.—Additional information is needed on the mechanical properties of welds, made by all methods using optimum procedures, in representative plain cast irons. Practically no such information is available on the properties of welds in the newer alloy and high-strength irons. Much of the physical property data reported is incomplete and difficult to correlate because full details of welding and test procedure is not stated. For this reason there is need for a standard test procedure for welds in cast iron which should include the size and shape of test welds and amount of discard and dimensions of test specimens and the testing procedures. Tests made should include tensile, transverse, hardness, repeated impact and fatigue on which some scattered information is now available. Nothing appears to be known of the compression, torsion, wear, corrosion and high- and low-temperature properties of cast-iron welds.

8. Welding Cast Iron to Other Metals.—There is developing a definite need for welding procedures for joining cast iron to steel and other metals, the purpose being to secure the favorable properties of cast iron at certain points in the fabrication. While some work has been

† Univ. of Michigan.

done on these composite welds additional investigation is needed which should include some of the newer alloy cast irons. Problems of differential thermal expansions and shrinkage stresses are involved in this work.

9. Special Methods of Welding.—It is reported that two pieces of cast iron cannot be resistance welded together but that cast iron can be so welded to steel. From the production standpoint it would be of value to determine the limits of compositions and microstructures of irons which can be resistance welded. The atomic hydrogen process said to be unsatisfactory for cast iron should also be studied further.

10. Nature of the Bond in Bronze-Welding.—There are differences of opinion and conflicting experimental evidence as to the best type of flux and procedure for bronze-welding, which in turn affects the condition of the cast iron surface being welded and the nature of the bond between the iron and bronze. In view of the widespread use of bronze-welding for cast iron further fundamental studies are desirable. Chemical studies of possible alloying of the iron and bronze, while difficult, would aid along with metallographic and physical tests in solving this problem. Little seems to be known of the use of bronze electrodes for welding.

11. Monel and Nickel Filler Metal.—Due to the fact that neither copper nor nickel form compounds with carbon, the problem of hard fusion zones should be reduced using an alloy of these metals. Some investigators have found this to be true while others have not. Further work on this problem is indicated which should include studies of cooling rates, fluxes, microstructures and physical properties of the weld and deposited metal.

12. Flame Cutting.—Whether flame cutting of cast iron involves principally melting or burning and the limits of composition and graphite structure where these two phenomena become predominant has not been definitely determined. Studies on the composition of slags formed from cutting irons of varying graphite structures would help to clarify this problem. Studies of the hardness and microstructure of the cut surface and heat-affected zone are needed accompanied by investigation of checks and residual stress which affect the properties and strength of flame cut parts.

IMPACT TESTS OF WELDS

By PROFESSOR O. H. HENRY†

NOTCH IMPACT

Of the different impact tests, each of which appears to be affected by and measure entirely different characteristics of the specimen, the notch-impact test is still the most frequently used for welds. Results to date show that for a given ordinary Charpy or Izod notched specimen at the ordinary speeds attainable in the usual pendulum machine, notch-impact value is affected by the following major factors: aging, deoxidation, grain size, alloying elements, martensite, "burning" and defects. Let us study each of these major factors to see which offers major problems for solution by the welding researcher.

AGING usually has a bad effect on notch-impact value, although the nature (particle size and location) of the precipitate is important. The nitride problem in mild steel welds made by bare electrodes may be considered solved. No other metal seems to be troubled by pick up of elements from the atmosphere during welding. However, some precipitation hardening alloys occasionally must be welded under conditions which make subsequent heat treatment impracticable, e.g. Duralumin. In every case the question may arise: WHAT WELDING PROCESS AND PROCEDURE HAS LEAST EFFECT ON NOTCH-IMPACT VALUE? The investigation may be based on specimens subjected to treatments calculated to duplicate the effects of welding in the different heat-affected zones, or the investigator may notch the heat-affected zones of welds.

The DEOXIDATION factor is important in steels. Low-carbon steels deoxidized with elements such as aluminum, vanadium and zirconium have good notch-impact value even down to −120° C. In this, may lie the explanation of the observation that weld metal from covered electrodes sometimes has better notch-impact value than plate metal at low temperatures. All deoxidizers are not equally effective, which brings up the problem: WHAT IS THE RELATIVE EFFICIENCY OF DEOXIDIZERS IN WELD METAL, PARTICULARLY FROM COVERED ELECTRODES IN MULTILAYER WELDS, IN MAINTAINING GOOD NOTCH-IMPACT VALUE AT LOW TEMPERATURES? The question might be answered by a series of notch-impact tests on all-weld-metal deposited by different electrodes, the composition of electrode, covering and deposit being known. Apart from the grain size factor, the effect of different deoxidizers in plate metal hardly can be affected by welding process. Consequently, data now available on plate metal in different heat treatments appear to provide sufficient information for such application as the low-temperature notch-impact value of flame cut surfaces.

The type of deoxidation used for copper is important but its effect on notch-impact value appears to be unknown, if relatively unimportant.

GRAIN SIZE in steel is closely connected with the deoxidation factor. Coarse grain structure is generally associated with poor notch-impact value. Widmannstatten structure in plate metal in the vicinity of the last bead in multilayer welds, or on all sides of the weld in single-layer butt and fillet welds is probably bad for notch-impact value but the magnitude of the effect is not clearly known. Tests on specimens heat treated to structures similar to those found in different heat-affected zones show that notch-impact value decreases as grain structure is coarsened. The austenite grain size appears to be the controlling factor here. Still if a zone of relatively coarse grain structure is backed up or supported by a fine grain zone of high notch-impact value, is the notch-impact value of the aggregate decreased in proportion to the relative thickness of the coarse grained zone? The problem is TO DETERMINE THE NOTCH-IMPACT VALUE AT DIFFERENT TEMPERATURES OF SPECIMENS HAVING KNOWN PROPORTIONS OF COARSE AND FINE GRAIN STRUCTURE BACK OF THE NOTCH. The base of the notch should be coarse grain in some specimens, fine grain in others, and half and half in still others. Care should be taken that the effect of grain size is not obscured by other factors, such as martensite or precipitation of copper. The specimens might be prepared from welds or locally flame-treated specimens of fine-grained steel. The Widmannstatten structure should be fine pearlite in all specimens in order that the effect of degree of aggregation of carbide might not disturb the pure effect due to the location of the ferrite with respect to the pearlite in the coarse structure.

The grain size is an important consideration for notch-impact value in welds in the higher chromium stainless irons, as well as in some non-ferrous metals, probably. There are data for the welded stainless irons, although very little appears to be possible by way of improvement

† Polytechnic Institute of Brooklyn.

even at high speeds of welding, but there is practically no information on the non-ferrous metals.

ALLOYING ELEMENTS may affect the notch-impact value depending on whether the alloying element is in plate or weld metal or both. Obvious problems are:

1. NOTCH-IMPACT VALUE OF WELD AND HEAT-AFFECTED ZONES IN WELDED LOW-ALLOY STEELS AT DIFFERENT TEMPERATURES. Apart from deoxidizer effects some elements are known to have a large effect on the notch-impact value of welds in low-alloy steels. What governs the effect of a given element in this connection appears to be unknown. Data are available for some combinations of alloying elements, but are lacking for others.

2. NOTCH-IMPACT VALUE OF WELD AND HEAT-AFFECTED ZONES IN WELDED NON-FERROUS ALLOYS. Practically none of the non-ferrous alloys has been seriously studied, although Monel metal, among others would appear to be worth investigation. The usual procedure of notching the weld and the different heat-affected zones as revealed by micrographs would be appropriate.

The effect of MARTENSITE on welds is primarily connected with steel containing above about 0.25 C, although some alloy steels of lower carbon content are also suspected under severe condition of cooling. Martensite (not tempered martensite or "martensitic structure") is known to have low notch-impact value and has been definitely detected in the heat-affected zones of steels which were pearlitic before welding. The problem is: WHAT ARE THE EFFECTS ON NOTCH-IMPACT VALUE OF LOCAL OCCURRENCES OF MARTENSITE OF DIFFERENT RELATIVE PROPORTIONS WITH RESPECT TO FERRITE-CARBIDE STRUCTURES, IN THE HEAT-AFFECTED ZONES OF WELDS. The same method of investigation as that recommended in the discussion of grain size (Widmannstatten structure) would be appropriate. A more informative study might be based on Meunier and Rosenthal's method of depositing weld beads on the surface of a steel at different speeds of welding, of notching the bead down to the heat-affected zone and of testing the specimen so formed. Hardness measurements according to Theisinger's method, as well as microscopic examination would also be made. In this way any relation that exists between maximum hardness in the welded area and the notch-impact value could be determined.

The results of "weld quench" specimens in investigating the effect of microstructural constituents on notch-impact value cannot be directly applied to welds where a brittle zone may be surrounded by material of high notch-impact value. Different results may be obtained, for a heterogeneous specimen of this sort if the crack is propagated from brittle to ductile material or vice versa. Extreme examples are mild steel welded with austenitic electrodes (in which a notch-impact crack propagated in either material does not tend to follow the very narrow martensitic area of junction between weld metal and plate) and bronze-welded cast iron. THE NOTCH-IMPACT VALUE OF BRONZE-WELDED JOINTS IS A NEGLECTED SUBJECT.

By "BURNING" is meant the melting during welding of the more fusible parts of an alloy having a long range of temperature between liquidus and solidus. Although not the accepted definition, this one is convenient for the present discussion. Several consequences of burning are of interest to those studying notch-impact testing. In the first place the low-melting material might run out of the plate metal in some parts of the heat-affected zone during vertical welding, thus leaving voids. Such an occurrence has never been observed. Second, low-melting material may flow to the line of junction between weld metal and base metal. Without producing voids, this flow might build up a brittle zone next to the weld metal. The effect is said to occur in some steels and bronzes. If the reported action does, in fact, occur, its effect on notch-impact value should be studied.

DEFECTS are a source of low notch-impact value. In general voids and slag inclusions lower the notch-impact value of welds as they do plate metal. No problems are suggested.

TENSILE IMPACT

The tensile impact testing of welds is in the stage of early development. Important research problems that should be investigated are so numerous that only a few need be mentioned.

1. EXPLORATORY TENSILE IMPACT TESTS AT RELATIVELY LOW SPEEDS OF COMMERCIAL WELDS IN ALL THE COMMON METALS AND ALLOYS OF ENGINEERING CONSTRUCTION WITH AND WITHOUT HEAT TREATMENT. This is a large order but an important one.

2. THE "CRITICAL SPEED," IF ANY, FOR WELDS MADE BY THE MORE IMPORTANT PROCESSES IN THE MORE IMPORTANT METALS AND ALLOYS AT DIFFERENT TEMPERATURES.

There are, of course, many other problems but none seems so important as the two that have been mentioned.

TORSION IMPACT

The Application of the Torsion-Impact Test to the Study of Welded Aircraft Tubing.—Disregarding the reheating effect of the beginning of the weld by the end of the weld, the torsion-impact test might be a useful method for testing all kinds of butt-welded tubing and pipe. Thin material could be tested as well as solid bars. No relation has been found between the torsion-impact test and other forms of impact testing.

REPEATED IMPACT

Although the repeated impact test has provided some interesting information on the "impact fatigue" resistance of welds, the test still eludes precise control. There are so many factors that affect the results obtained on existing repeated impact machines that their application is extremely limited and is declining. Although he should keep repeated impact in mind the welding researcher must await fundamental developments in repeated impact testing methods before he can satisfactorily test welded joints.

MISCELLANEOUS

The explosion impact tests recently performed by U. S. Steel Corp. literally open up a new field of investigation. It would seem that tests on a smaller scale might be a bit less hazardous, but detailed suggestions for further research, of course, must await the detailed analysis of the results obtained thus far.

What is the impact value of spot and seam welds?

DISCUSSION BY PROFESSOR M. F. SAYRE

1. The particular problem which, at the present moment, is attracting the greatest interest is that of the meaning of impact tests of various kinds, and also the determination of the effect upon impact value of various

modifications in welding methods. Professor O. H. Henry, of the Polytechnic Institute of Brooklyn, has suggested the following problems in this connection:

A. What is the relative efficiency of deoxidizers in weld metal, particularly from covered electrodes in multilayer welds, in maintaining good notch-impact value at low temperatures?

B. Determination of notch-impact value at different temperatures of specimens having known proportions of coarse and fine grain structures back of the notch.

C. Notch-impact value of weld and heat-affected zones in welded low-alloy steels at different temperatures.

D. Notch-impact value of weld and heat-affected zones in welded non-ferrous alloys.

E. What are the effects on notch-impact value of local occurrence of martensite in the heat-affected zones?

F. Notch-impact value of bronze-welded joints.

G. Application of the torsion-impact tests to the study of welded aircraft tubing.

H. "Critical speed" in tensile-impact tests of welds made by the more important processes in the more important metals and alloys at different temperatures.

2. Other possibly important problems which concern particularly the details of weld testing:

A. Effect of aging upon apparent ductility in bend and tension testing. Is it desirable or advisable to include in specifications any limitations as to minimum or maximum length of time between preparation of weld and testing of specimen?

B. In tests of pipe welds in tension, is anything gained by machining of specimens to rectangular cross section as against relying on flattening of the specimens in the grips themselves?

C. Is the density test on all-weld-metal of sufficient value to justify its continued use?

D. If the forced bend method as called for in existing Navy specifications, is to be continued in use, to what extent should more detailed instructions be included in the specifications for the making up of the specimens and the carrying out of the tests in order to obtain satisfactory reproducible results?

3. Another question of fundamental importance concerns the development of additional information on the fatigue strengths of welds and welded structures, based upon tests on large size specimens. A program to accomplish this result is, however, already under way.

DISCUSSION BY MEMBERS OF COMMITTEE ON METHODS OF TESTING, I.R.D.

C. E. Loos, American Bridge Company

All the items enumerated under impact testing should be investigated, but our chief concern is the impact value of welds made in cold weather on 0.15 to 0.25% carbon structural steel. The items mentioned under headings 2 and 3 are believed worthy of investigation.

Two additional problems should be added to the list:

The first is a standard method for preparing all-weld-metal test specimens. Results of such tests vary for the same grade of electrode with different weld procedures and atmospheric temperatures. The size of the material forming the groove into which the metal is deposited, the number of passes and time allowed for cooling between passes are all variables that influence the final results.

The second problem is to establish the worth or worthlessness of a tensile test specimen by some inspecting bureaus, such as the American Bureau of Shipping. The section now tested is a machined V butt weld $^3/_8$ inch thick, $1^1/_2$ inch wide at reduced section, $^3/_4$ inch radius. The quality of weld metal will vary from the plate strength of 60,000 to 65,000 lb./in.^{2} to 75,000 to 80,000 lb./in.^{2} with the result that the fracture may occur anywhere from the minimum section of the welded joint up into the parent metal itself. The use of such test specimens should be discouraged and can best be throttled by an organization such as the Fundamental Research Division.

A. B. Kinzel, Union Carbon and Carbide Research Laboratories

Problems 1*A* and 1*B* are steel problems rather than welding problems. Problem 3 is important, 2*A* is, and 2*B* are not important, 1*C* is important at low to moderate temperatures only, and 1*D* should be carried out on all copper alloys. An additional problem is:

"Effect of welding low-alloy steel with rods of different composition. In the opinion of many, this is highly desirable."

I. T. Hook, American Brass Company.

1*A* to 1*C*. Information on these projects would be desirable, more particularly as they apply to steel. Project 1*A* is a rather comprehensive investigation and would not be undertaken for notch impact alone—all other properties would be investigated as well.

1*D*. Information desirable but not as important as the tensile and elongation values of welds and weld metal.

1*E*. Applies only to steel having medium and high carbon.

1*F*. Desirable information. Location of notch, i.e., on face or root of weld or in all-weld-metal specimen must be stated.

1*G* and 1*H*. Desirable information on steel tubing. "Critical speed" of tensile-impact tests of welds at different temperatures should be shelved until we know more of this property of the base metal.

In planning tensile-impact tests on metals as soft as welded copper, a specimen having a relatively thick gage length should be used. Small threaded specimens of copper having a diameter of 0.200 inch in the gage length are too delicate and too expensive to machine.

2*A*. Important on tests at room temperature only for those alloys age hardening at room temperature as is the case with some aluminum alloys. When testing precipitation hardening alloys at elevated temperatures, the time required to bring to temperature of test is very important.

2*B*. Pipe welds in sizes up to 2 inches actual outside diameter should be tested in full size. For larger pipes, longitudinal elements cut from the welded length need not be flattened for pulling.

2*C*. The density test on all-weld-metal is a rather poor second to the X-ray or the tensile test.

2*D*. I believe this Navy Specification calls for $^3/_8$ inch thick base metal. The shape of the weld groove, spacing of edges, character of backer, size of welding rod and number of passes could be given. The arc voltage and current cannot be specified until all the materials and conditions are known. In other words, the determination of the optimum arc settings is a cut and try process with every change in the materials or conditions of usage.

3. Not, in general, important for copper alloys. The "breathing test" on copper alloy range boilers is a special production test not closely related to fundamentals.

H. V. B. MADSEN, Bureau of Construction and Repair, Navy Department

It is believed that the list covers problems, the solutions of which will be of great value.

In the opinion of this Bureau, however, it is questionable if the solutions can be reached by means of the notch-impact test. It is believed that in the final analysis, it is the impact strength of the welded joint in which we are interested. The use of the notch necessarily removes a portion of that joint, and in addition the metal under the notch will not be uniform in structure throughout its cross section so that it will be difficult to determine the exact feature which was responsible for the particular impact value obtained.

As a possible alternative, it is suggested that the tensile-impact test on unnotched specimens be used, and that either the testing specimen or a specimen taken adjacent to the testing specimen be examined metallurgically in order to determine the cause of failure.

In connection with paragraph 3 of the tentative draft, it is noted that fatigue tests of welded structures are contemplated, and that a program is under way. Inasmuch as this Bureau is interested in this subject, and is conducting tests of a similar nature, it is requested that if possible information be forwarded as to the nature of the tests and the testing agency.

Other Research Problems

(Suggested by Various Experts)

WELDING CAST STEEL

1. Base Metal. Complete investigations of physical properties, welding characteristics, and hardness penetration of low-alloy cast steel welds, particularly of cast steel containing copper.
2. An investigation of welding cast steel (plain carbon) with low-alloy, low-carbon or austenitic filler rods.
3. If weld metal and junction zones are not more coarse grained than heat-treated casting, is heat-treatment above 600° C. (stress-relief) necessary?
4. Shrinkage Stresses in cast steel welds.
5. Low-temperature tensile properties of cast steel welds.
6. Fatigue and vibration tests of welded cast steel structural elements.
7. The thermal expansion of weld metal compared with cast steel of the same composition.

WELDING WROUGHT IRON

1. Impact and fatigue properties of arc- and gas-welded wrought iron.
2. Properties of bronze-welded wrought iron.
3. Welding of wrought iron alloyed with nickel (metallurgy and testing).
4. Welding of galvanized wrought iron (procedure and properties).
5. Metallography and properties of flash-welded wrought iron.
6. Strength of spot welds in heavy wrought iron plates ($^1/_4$ inch to $^1/_2$ inch thick).
7. The slag question in welding wrought iron with covered electrodes? Do some coatings tend to entrap slag in the weld, as stated by reference 33.
8. The relationship among power, pressure, upset, slag content and mechanical properties and structure of resistance butt-welded wrought iron.

PHYSICS

The current problems in the physics of welding are largely indicated in the appended references to recent literature on gas welding, arc phenomena, and non-destructive tests. The following problems are outstanding.

1. Mechanism and rate of metal transfer in arc welding, including overhead welding and controlled atmospheres.
2. Laws governing magnetic disturbances in A.C. and D.C. arc welding and how these disturbing effects may be eliminated.
3. The effect of alloying elements, such as manganese, and of multi-constituent coatings on arcing characteristics of the electrode. The effect of a large number of single coating constituents being known now, it would seem most desirable to determine their combined effects as in commercial coatings. Perhaps a spectrographic study providing information on the excitation of coating components singly and in combination might usefully supplement the oscillographic mode of attack on stabilization problems.
4. D.C. and A.C. arc temperatures with various metals and alloys, in various atmospheres, and over a wide range of amperage.
5. Calorimetric Study of Carbon and Metal Arc and Gas Welding.—This study would be of great practical value if the heating effect of various conditions on the material being welded could be determined quantitatively. Such results might lead to methods of predetermining amounts of shrinkage by mathematical analysis.
6. Theory of Combustion in the Oxyacetylene, Oxyhydrogen and Other Welding Flames, and Metal Transfer During Welding with These Flames.—A spectroscopic examination of different regions of the flames using various gas ratios, with and without introduction of the welding rod would probably suggest means for more efficient gas welding procedures.
7. A quantitative study of the path of the current in resistance welding, particularly spot and seam welding. It has been suggested that the current path for small current and thick plates could be determined. The path for thin sheet and high current might then be mapped approximately by extrapolation. The current distribution in resistance butt welding bars whose ends are slightly conical should also be determined.
8. Non-Destructive Tests of Welds.—(*a*) Correlation between X-ray photographs and specific gravity, nick-break test and physical properties. This investigation should include a quantitative check on several qualitative X-ray tests that are used in some quarters.

(*b*) Investigation of the supersonic vibration method and its sensitivity to common defects in welds.

(*c*) Investigation of electrical and magnetic methods of weld testing with particular reference to fillet welds.

9. The Nature of the Bonding Force in Welding.—If the base metal is not melted, as in brazing, the bonding forces are created by intercrystalline penetration of filler metal into base metal, and by diffusion into or absorption on base metal. During welding, the base metal is melted

and the molten filler rod simply increases the volume of metal that subsequently solidifies. The problem is to study the nature and strength of the bond between base metal maintained at different temperatures and molten metal poured on its surface. Information obtained from these tests, admittedly difficult to control, might then be compared with the strength of joints in solid-solid and solid-gas "welding." The solid-solid weld is controlled by a balance between sintering temperature and pressure, and probably its strength is primarily an expression of mutual absorption forces unless as in electrodeposition, the coating adherence may be controlled by valency effects. The nature and strength of the adherence between base metal and sublimed deposits is affected to a great extent even by monomolecular absorbed films of oxides, for example, which are particularly disastrous in solid-solid or pressure welding. Solid-gas welding has been observed in some reversed polarity arc welding; solid-solid welding undoubtedly plays a part in resistance butt welding.

WELDING PROCEDURE

Apart from proprietary methods there is much to be done on the most satisfactory procedures for welding metals and alloys by all processes. The conflicting statements that occur in recent literature on welding alloy steels and non-ferrous metals are proof that well-planned experimental work is urgently needed, including a study of welding variables as well as of physical properties and microstructure of the welds. It is time that opinion and fragmentary information should be replaced by demonstrated facts.

1. Speed of welding and the relation between voltage and amperage. A record of the power consumption at the arc with these tests would provide definite information along a direction in which very uncertain information now exists. There is an analogous problem in gas welding, namely, the relation between welding speed and gas consumption.

2. Proper welding procedure to obtain satisfactory welds in hydrogen and other gases. The experimental work on this problem need not involve the actual making and testing of welds since the chief problem is the amount of metal discharged from the tip of the electrode. Automatically controlled experimental conditions should preferably be adopted.

A careful study should be made of the amount of electrode melted down with different arc voltages from the lowest to the highest practicable and also with the lowest and highest current densities practicable for any size of electrode. Different combinations of experimental conditions should be tested and a record made of the rate at which the metal is melted and also the rate at which it is deposited Bare and covered electrodes, ferrous and non-ferrous, should be investigated, along with D.C. as well as A.C. and atomic hydrogen.

The objects of these experiments would be to determine the nature of metal transfer, to determine if there is an optimum current density applicable for all sizes of electrodes, to discover the effect of electrode composition on deposition efficiency, as well as a number of other features which the experimenter would realize as the work progressed.

3. Effect of peening on the quality of welds. Although it is known that peening reduces shrinkage stresses in welds in mild steel up to 50%, it is still a question whether peening has a favorable effect on impact or fatigue value. The temperature range in which peening is done and the point at which the blow is struck are the two major factors. Some believe that peening the weld metal is undesirable but that peening the base metal adjacent to the weld is helpful. It is suggested that experimental peening be performed with an air hammer supplied with a constant air pressure.

4. Capacity to produce resistance welds of constant quality in different individual and total thicknesses of material using a given setting of the machine. Tests to determine optimum current, pressure and dwell for all resistance welding processes, as determined by physical properties and economy.

5. Effect on resistance welding of coatings such as dirt, oxide and zinc, nickel, tin or other platings on steels, brass and other alloys.

6. A comparison of forehand and backhand gas welding for non-ferrous alloys. The comparison should include the time of welding for various plate thicknesses ($^1/_{16}$–$^1/_2$ inch), gas consumption, fatigue of operator and quality of welds.

7. The effect of annealing above or below the critical point on the physical properties and machinability of welds. The tests should be directed particularly toward improving gas, arc and resistance welds in high carbon and alloy steels and cast iron. The problem is particularly acute in welding two steels having widely different critical ranges.

8. Spot welding precious metals and alloys.

STRUCTURAL STUDIES

The greatest advantages to be obtained by the use of welding in fabricating structures of all kinds can only be obtained by adopting structural methods suited to welding. At present the influence of joining processes, such as nailing, pinning and riveting, which are basically different from welding, is felt to too great an extent in welding design. But the best design methods for welded structures can only be developed on the basis of experimental studies of the stress distribution and shrinkage of welded joints. The references to recent literature on these topics shows that considerable progress is being made; yet a number of fundamental problems are still unsolved.

1. Stress distribution in full-scale welded structures. Experimental and mathematical analysis of stress distribution in beam and column connections and in built-up girders should be made in order to deduce reliable design formulas and to determine safe design practice. Experimental studies should take weld shrinkage into account.

2. Photoelastic studies of the stress distribution in welded joints. Although the technique of the photoelastic study of welded joints appears to have been worked out, there are relatively few quantitative data on the magnitude of stress concentrations in typical welded connections; for example, transverse and diagonal butt joints with intermittent welds, several common marine types of lap joints, turned-up sheet welds, welded stiffening webs and plates in beams, crossing butt welds in all pressure vessels; pinned or riveted strap joints strengthened by welding, right angle butt welds. In addition to the information obtained from photoelastic models containing no defects, it would be very useful to know the maximum increase in stress concentration created by typical defects such as blowholes, undercut and faulty penetration. Thus, the maximum stress concentration should be determined in corner welds of various types with poor root penetration.

3. The degree of restraint that may be counted on in welded beam connections. The quantitative study of

rigidity in welded construction has been advanced by vibration studies of bridges and machine tools but a great deal of information is still required. A particular problem is the relative value of welding rotor hubs to shafts compared to press or shrink fits.

CHEMISTRY

1. The chemistry of fluxes and coatings. (*a*) Viscosity, melting and boiling points, and surface tension of typical flux and coating compositions.

(*b*) Is the action of the coating on coated or shielded arc electrodes in excluding nitrogen mechanical or chemical? Experiments should be made in which a weld is made in air or nitrogen with a coated electrode, and then with a bare electrode using a flux of the same composition as the coating. The weld metal and slag in both experiments should be analyzed, particularly for nitrogen. If the action of the coating is mechanical, that is, if the volatilization of carbonaceous or other material forms a mechanical shield around the arc despite the turbulent conditions, then the second weld may be expected to contain nitrogen. If the action is chemical both welds will be free from nitrogen and the gases around the arc (which might be analyzed perhaps partly by spectroscope) or the slag itself will contain stable nitrogen compounds.

2. Corrosion of welds.—The recent review of literature on the corrosion of welds shows that the following problems require study:

(*a*) The rate of corrosion of all kinds of welds in various atmospheres and media at different temperatures.

(*b*) The theory of the corrosion of welds. Some of the factors that are said to affect the corrosion properties of welds are: (1) Rough surface of weld; (2) difference in electrode potential of weld metal due to difference in chemical composition, in microstructure and in other properties; (3) slag content in and around weld metal; (4) highly stressed condition of unannealed weld metal and adjacent base metal. The relative importance of these factors should be estimated for welds in ferrous and non-ferrous materials.

(*c*) Procedures for testing the corrosion properties of welds. Accelerated methods are not necessarily implied. A procedure for obtaining the maximum measurable corrosive effect under service exposure is required using specimens of convenient size prepared under normal welding conditions.

(*d*) The effect of corrosion on the mechanical properties of welded joints in heat-treatable alloys. Welding sometimes sensitizes the heat-affected zone of alloys to intergranular or accelerated corrosion. The problem has been studied to exhaustion in 18–8 and closely related alloys but has been neglected in light metals and copper alloys.

METALLURGICAL

1. Study of series of alloy steels varying by only one element, such as nickel, chromium, molybdenum and vanadium. Determinations of hardness and bend ductility should be made. It should be remembered that alloy steels are not welded indiscriminately by the same procedure; in experimental work it is essential that changes in procedure be studied before conclusions are drawn.

2. Effect of preheat temperature on hardness produced during the weld quench, and arrangement of alloys into groups depending on the preheat required to maintain a standard of bend ductility adjacent to the weld.

3. Flame hardening with the oxyacetylene torch, using alloy steels (air and water hardening) and possibly non-ferrous alloys, such as duralumin and beryllium-copper. The metallurgical effects are different in spot and straight line hardening and especially in closed circle hardening where the end effect is important.

4. Surface tension effects of different types of weld and brazing metal on steel, copper and alloys in general. Surface tension, which has a large influence on penetration and weldability, should be studied with strict control of atmosphere and metal composition, and with adequate consideration of fluxes and slags.

5. The metallurgy of welding difficult metals and alloys under water or other liquids, such as carbon tetrachloride.

6. The metallography of austenitic welds in pearlitic cast iron. A microscopic and hardness survey of welds (cold and preheated) made with several types of austenitic filler rods in a single common grade of pearlitic cast iron would reveal the sources of defects as well as the probable field of application of each rod. A related problem is the metallographic study of welds made with high-chromium rods to determine the extent and effects of nitrogen pick-up, either from the atmosphere or from high-nitrogen base metal.

7. Assembling complicated magnets of nickel-aluminum and other magnet steels by fusion welding followed by suitable heat treatment.

8. Carbon migration in flame cutting. The literature of 1937 contains at least two references to the alleged fact that during flame cutting of plain carbon steels, especially over 0.30% C, some carbon from the interior of the steel diffuses to the layer of steel just back of the cut edge. This carburized layer is quite distinct from carbon that may be derived from the preheating flame. In other words, the flame-cut surface of a plain carbon steel cut with a preheating jet containing no carbon, an oxy-hydrogen preheating flame, for example, will contain appreciably more carbon than the body of the steel, which will have supplied the increase at the edge. Presumably the hypothesis is that the layer of steel adjacent to the cut edge is heated into the austenite region during flame cutting, and austenite, having a greater solubility for carbon than ferrite, absorbs carbon from the ferrite with which it is in contact. The hypothesis has not been refined to the extent of considering the Delta region in which the carbon solubility is also small, unless the statement that the carburizing effect is particularly marked in steels containing over 0.30% C may be so interpreted. A few carbon analyses on selected cuts probably would settle the question once for all.

9. Grain size characteristics of welds, particularly in steel. Beyond the fact that welded joints in structural steel made by gas or arc processes may be fine grained or coarse grained in weld metal and heat-affected zone depending principally on the number of passes, very little is known about the grain size characteristics of present-day weld metals. It is not safe to apply the data available on grain size of open hearth or bessemer or electric steel to weld metal of similar composition because grain size characteristics are notably dependent on melting practice. The conditions under which weld metal is produced are radically different from those prevailing in the steel furnaces. In the steel furnaces the slags are either predominantly basic or predominantly acid, and are made up principally of CaO, SiO_2, FeO and MnO. Welding slags are usually of an entirely different nature, the deoxidizer frequently being titanium or other unusual element.

10. Hard-Facing. Some of the questions in hard-facing are:

What is the effect of thickness of layer on the bend value of faced surfaces?

What is the fatigue strength of hard-faced bars?

What shrinkage stresses are induced in hard-faced parts, and what heat treatment or mechanical treatment may stress relieve them?

What is the extent of penetration of hard-facing into base metal and vice versa (quantitative as a function of facing procedure)?

What is the hardness of hard-faced parts as a function of thickness of deposit and method of hardness testing?

What is the thermal coefficient of expansion of hard-faced bars?

What happens to the wearing properties of a hard faced part when the base metal is exposed in spots?

First Steps in Welding Research

To those who have from the foregoing lists selected problems which appeal to their research sense, but who have had no previous experience in welding research, the following step-by-step procedure may be helpful. The Chairman of the Division invites inquiries from any welding researcher on any item in the procedure.

While it is quite contrary to the aims of the Fundamental Research Division to standardize methods of research and to let ourselves get into a groove, it is important that welding researchers be acquainted with the assistance they may expect from the Division. It is the Division's experience that for a number of reasons much time and anxiety often are wasted by those commencing research on a new subject such as welding. The Division has found that welding researchers adopting some or all of the steps outlined in the procedure make more rapid progress than otherwise.

1. *Facilities and Time.*—A problem having been selected, the researcher should take stock of the laboratory facilities that he possesses. For example, research on welding arcs or the resistance welding circuit usually requires the use of an oscillograph or of special power meters. If the researcher finds that the investigation of his problem demands special instruments which he does not possess, he need not abandon his plans until he has made sure that he is unable conveniently to borrow the special equipment from another welding research laboratory, or that the time he has available does not permit his constructing an elaborate apparatus. The instrument designer and maker has made possible some of the most significant discoveries in welding.

2. *Library Research.*—The Committee has prepared reviews of literature on a number of topics. If the researcher wishes detailed information on any literature references not available to him, the Committee is prepared to furnish it, if possible. Upon request, the Committee will assist also in compiling a bibliography on the subjects of interest to the researcher.

3. *Local Section Meetings.*—If the research worker will attend the technical meetings of his local section of the AMERICAN WELDING SOCIETY even though he is not a member, he will become acquainted with engineers in the welding field who will be glad to discuss the research problem with him.

4. *Conventions.*—Special arrangements are made to facilitate the attendance of welding researchers at the Annual Meeting of the AMERICAN WELDING SOCIETY.

5. *Visits to Local Firms.*—Generally the welding researcher will find it worth while to make one or more plant visits to familiarize him with commercial welding operations. If necessary, the Division will secure an introduction for the researcher to a plant engaged in the manufacture or use of the welding equipment or progress in which he is interested. An exchange of views between the researcher and the firm's representative is always profitable.

6. *Correspondence with Other Researchers.*—Several members of the Division often carry out research on the same general topic, e.g. fatigue, resistance welding. Correspondence among these members keeps each informed of the other's progress and prevents duplication of effort. The Division is ready to assist in starting such correspondence between members new to the particular field of research and other members in both the Fundamental and the Industrial Research Divisions who have acquired experience in it.

7. *Specimens.*—Lack of welding equipment need not deter the research worker. Specimens of the type desired by the researcher can usually be obtained through cooperation between the Division and commercial welding firms and laboratories. The researcher should specify welding process, dimensions (blue prints), and quantity in sending his requests for specimens to the Central Office.

8. *Visits by Members of the Division.*—Visits are periodically made by the Chairman of the Division. Mr. H. M. Hobart, or one of his representatives, to as many of the members as possible. Several important investigations have originated in these visits.

BIBLIOGRAPHIES

References to 1937 welding literature on topics that have not yet been made the subject of Reviews by the Literature Division are given in the following appendices for the convenience and assistance of welding research workers. A review of literature on welding alloy steels being in progress, this subject has not been dealt with in the appendices. Papers in the AMERICAN WELDING SOCIETY JOURNAL and Research Supplement are not given detailed analysis in the appendices because the JOURNAL is generally accessible and regularly read by members. The references are almost entirely to 1937 publications and are not to be considered in any way as critical reviews of literature. References to recent welding literature were also published in the Research Supplement for November 1936 on the following topics:

I. Effect of Carbon on the Properties of Fusion Welds in Steel
II. Effect of Silicon on the Fusion Welding of Steel
III. Effect of Manganese on the Properties of Fusion Welds in Steel
IV. Welding Alloy Steels
V. Welding Non-Ferrous Metals (Excluding Copper)
VI. Welding Cast Iron
VII. Resistance Welding Electrodes
VIII. Metal Transfer in Welding and Allied Topics
IX. X-ray Weld Testing
X. Weld Shrinkage

XI. Stress Distribution in Welded Joints
XII. Corrosion of Welds

NOTE: The superior numbers throughout the texts refer to the bibliography which is appended to each section.

APPENDIX I

Resistance Welding

Spot and Seam Welding

Theory

The theories of spot welding, if there are any worthy of the name, are not yet in a highly developed state. The phenomena which control spot welding are largely conjectural at the present time. Fassler[1] makes it clear that purely machine factors have a preponderating influence on welding. After dividing the spot welding operation into three steps: (1) squeeze to maintain contact (2) current to raise the temperature (3) increase in pressure to secure proper bond, he goes on to say that power factor is most important. A manufacturer who replaced steel transformer housings by aluminum castings increased power factor by 15 to 30%. Conventional spot welders with 12-inch throat never have power factors greater than 0.6. Kva. ratings must be increased 25% for every increase of 6 inches in depth of throat. Fassler concludes his discussion by working out an example showing how a 12 kva. machine designed with particular attention to power factor can do the work of a conventional 50 kva. machine. There appears to be practically no literature on the design of spot welding transformers. La Cour's[2] textbook says a few words about an old cast secondary construction but gives no hint whatever of recent design.

There is a belief that contact resistance may play a part in spot welding and sticking of tips. However, Crampton and Vreeland's[3] research on the spot welding of copper alloys showed that the contact resistance measured at room temperature decreases greatly as the electrode pressure is increased and has little relation to electrical conductivity or spot welding characteristics. Possibly the contact resistance at elevated temperatures may turn out to be a more fundamental constant. Their investigation of the microstructure and physical properties of spot-welded copper alloys is of the first importance.

Kislyuk[4] confirmed the formula $R_c = \frac{Z_1}{PA}$ for the contact resistance at pressure P, when Z_1 is the contact resistance at a pressure of 1 kg. and A is a coefficient depending on the metal and the surface finish. In general, Crampton and Vreeland's measurements do not suggest a linear relationship but Kislyuk states that the relationship applies to mild and stainless steel, copper, duralumin and aluminum. He also analyzed in a general way the heating during spot welding and the heat losses in the electrodes and plates. Roulleau[5] has devised a refined method for measuring the contact resistance (up to several hundred millivolts) between a metal and a layer of Cu_2O, as in a rectifier.

Van Thijn[6] has derived a formula showing that the resistance in spot welding does not depend on the gage of the metal. An elementary theory of the spot welding circuit based on Joule's Law and the resistances between sheets and between electrode and sheet has been worked out by Frost,[7] who considers heat loss by radiation and by conduction to the work and electrodes, but is unable to make an assumption about thermal gradient or area through which heat is conducted. Using the differential equations for an inductive circuit, Mathieu[8] calculated the magnitudes of the factors involved in charging the primary of an induction coil and in discharging through a secondary circuit (the welding circuit) neglecting iron losses. He found that such a circuit required large coils and precise regulation, and that the ratio of energy derived from the secondary to the energy input to the primary per cycle was about 0.16.

According to Whitmer,[9] the depression at the spot in stainless steel is due to shrinkage of the molten metal in the center, and Mikhalopov[10] believes that cavities in spot welds in low-alloy steels are the result of vaporization of the steel. Both statements are open to question.

Controllers

Apparently far more research has been devoted to spot welding controllers than to any other phase of spot welding. As a result, the development of controllers has been astonishingly rapid. A survey of all types of timers and their accuracy with special reference to the Ignitron is given by Thomasson.[11] A French writer[12] also gives a general review of timers based on the following principles and combinations thereof: constant time, constant minimum current, constant ampere-seconds and constant watts. A general consideration of the factors involved in automatic spot, seam and gun welding by Landström[13] deals particularly with shop aspects. In an elementary discussion of seam welding Wilbert[14] points out that mechanical switches or rectifiers are used for control instead of changing the frequency to synchronize with the velocity of welding so as to space welds the distance of 0.06 to 0.08 inch apart, which experience shows is best.

Grid Type Tube Controllers

A summary of developments and circuits for Thyratron control of spot and seam welding is given in Henney's textbook.[15] Palmer[16] explains that Thyratrons are gaseous discharge tubes of the hot cathode type and explains typical circuits for seam welder control as well as combination spot and seam welder control. The secondary current is varied either by an autotransformer between the mains and the primary, or by changing the turn ratio by means of taps on the primary. A phase shifting circuit is described which determines the point on the A.C. wave at which the firing tubes will go into action.

For gas tight seam welds in 18–8 0.025 inch thick, Hutchins[17] recommends 2 cycles on, 2 off; for 0.032 inch mild steel: 2 cycles on, 1 cycle off. Rejects vary from 0.1% for 18–8 to 0.9% for mild steel with Thyratron control. The low power factor (0.3) and the form of a spot welder's throat, which introduces a comparatively high inductance in the secondary circuit of the transformer, explains the fact that the variation in current demand (24 to 30 inches throat) between one and several thicknesses between the electrodes is usually 5% or less. Transients of varying magnitude due to closing the circuit on different parts of the voltage wave cause different amounts of heat to be developed in the weld for the same (short) timing periods.

Schilling[18] analyzes the effect of closing the circuit on different parts of the wave by means of oscillographs. The cause of the effect is traced to the magnetizing current of the transformer. For example, with the transformer between the mains and the grid-controlled rectifier and with firing for 45° on the wave, the magnetizing current is symmetrical on switching in, but gradually shifts to decided assymmetry, the D.C. part of which gives rise to a D.C. flux, which is superimposed on an approximately sine wave A.C. flux, and to additional voltage drop. Peaks in the magnetization current develop in seam welding if the current is switched in

anywhere except at the peak (90°) of a current wave. As the pause between welds is increased the effect of the peak decreases.

The interrupted spot welding of thick plates with Thyratron control described by Pelton[19] consists of repeated power impulses. With pressure exerted throughout the operation 1-inch mild steel plates are spot welded in 1 minute by means of 30 applications of power, each 60 cycles long, with 60 cycles off between impulses. Two such welds in line in plates 3 inches wide with lapped surfaces broke at 118,000-lb. tension transversely through the axis of one of the spots. Taguti[20] explains the circuit of a 150 kva. Thyratron controlled spot welder for light metals (0.02 to 0.2 sec., up to 30,000 amp.). A French periodical[21] gives a brief description of the Sciaky Thyratron seam welder (0.02 sec. on, 0.04 sec. off) for 0.08 inch stainless steel. Another Thyratron controlled seam welder[22] (100 kva., 1 to 13 ft./min., 60 to 1500 interruptions per minute at one cycle on) for stainless steel can accommodate a combined thickness of $^3/_8$ inch and can weld terne plate or phosphor bronze to copper braid, among other things.

Mercury Pool Type Tube Controllers

Henney[15] devotes two or three pages to the Ignitron spot and seam welding controller, and Hall[23] gives an elementary description of it. Details of the manufacture of sealed-off Ignitrons are given by Packard and Hutchings.[24] These tubes handle up to 7000 amp. peak, 250 amp. average. An Ignitron $1^1/_2$ inches diameter, 3 inches long, will handle several hundred amp. Vedder and Dawson[25] state that the majority of spot welds *should* be made in less than 1 sec. down to $^1/_{120}$ sec., and recommend the Ignitron, which consists of three electrodes: (1) mercury pool (2) graphite (3) spark plug dipping into the mercury. When current flows through the spark plug there is an instantaneous arc discharge to the graphite. Correct welding current is checked by an ammeter with mirror actuating a photo tube and bell. Too little current gives no ring, too much gives two rings, correct current gives one ring.

A device for obtaining constant total heat energy during spot welding is the monitor described by Henney.[26] An air-cored toroidal coil surrounds one of the welding tips. The coil voltage is delivered in part to a diode whose characteristic follows a square law and thus is proportional to the square of the welding current. A condenser is inserted in series with the diode so that its voltage is also proportional to the square of the welding current integrated over the welding time. The condenser voltage is measured by means of a vacuum tube voltmeter, which, consequently, reads the total heat energy of the weld. Adjustments of a new machine's current and time are so made that the total heat energy of the new machine's welds is the same as that of welds made by other machines turning out satisfactory work. An autographic current-time recorder for spot welds has also been described.[27] The AEG modulator[28] for seam welding is built in the form of an A.C. motor which, when revolving at constant speed, sends a fluctuating voltage into the welding transformer.

The half-cycle spot welder control originated by Gray and Nottingham[29] embodies a mercury pool type tube ("band-igniter arc tube"), a type 80 rectifier tube, a Ford spark coil and a Strobotron, which is a neon-filled tube at 15 mm. pressure, caesium covered cathode, and two grids, 250 amp. maximum instantaneous anode current. The circuit is similar to the Thyratron. On account of the high currents (up to 300 amp. peak in primary) high electrode pressures are required for half cycle welds to provide the requisite forging action and prevent vaporization. Tests with varying electrode pressure and current on round nickel wires, 10, 35 and 50 mils diam., showed that 40-lb. pressure was best for 50 mil and 20 lb. for 10 mil (with reduced current) to obtain best strength. Sidorenko[30] has devised a means for igniting the Ignitron not depending on moving parts or on a large number of tubes. His device consists of transformers, choke coils, resistances and Cu_2O rectifiers. The application of the Kathetron external-grid mercury-pool voltage regulator (200 kva.) to 18–8 spot welding has been made by Craig.[31] The voltage regulator is sometimes more economical than the large transformers that are required without voltage regulation.

Other Controllers

The means whereby magnetic type controllers for seam welding can be made to control timing accurately from less than 1 cycle to 5 cycles are disclosed by Stansbury,[32] whose contactor operates on the principle of the hair spring and balance wheel of a watch. A short current impulse sets the contactor on its travel, during which its motion is determined by the mechanical arrangements of the system. Although inherently inflexible as far as adjustment is concerned, Stansbury found it easy in practice to regulate the time of contact over a considerable range, although he does not mention the minimum timing period of his contactor. A non-magnetic spacer prevents iron-to-iron seal on the magnet face, thus providing quiet operation without wear. A thyratron permits actuation of the contactor at any desired phase position.

The magnetic timer used by Roby[33] for pneumatically operated portable spot welders (up to 600 welds per minute) is not suitable for short welding times, because the magnetizing current transients resulting from energizing the transformer at the zero point of the voltage wave cause large variations in primary current and inconsistant welding results. Roby points out the desirability of a hold period after the welding current is switched off. There is less discoloration, grain structure and strength are better, heat does not travel ahead to cause sticking at the next spot and there is no breakage of welds in the plastic range. Barbour[34] found that, with several spot welders on the same power line, cold welds occasionally occurred when two machines fired simultaneously. The circuit diagram of the synchronous drive is explained, which was made so that each machine would be out of step with the others.

Machines

It is well known that machine settings will be somewhat different for different jobs in a given thickness of metal. Still, Thomasson's[35] table giving tip pressure (copper-chromium alloy tips), number of cycles (Ignitron), and percentage of machine capacity for spot welding aluminum, lead, zinc, brass, 18–8, tinned everdur, etc. (0.01 to 0.125 inch) provides interesting material for comparative study. It was not found practicable to make a spot weld in zinc $^1/_8$ inch thick which would tear a hole. The indentation was over 30% of the thickness in zinc, but was 10% or less in all other welds. Charts prepared by Hensel[36] show the variation of timing (1 to 10 cycles), pressure and current on spot welds in 18–8 and cold-rolled steel (0.040 inch thick) as a function of spot dimensions. Pressure must be increased as welding time is decreased and as thickness is increased. In "slow" welding clean cold-rolled steel the minimum pressure is 130 lb. at a total thickness of 0.079 inch, and 5500 lb. at 1.18 inches. Wilson[37] supplies a number of tables on the effect of time pressure, and current on weld area, but he grossly disregards his own plea that investigators of spot welding give all pertinent details. Crampton and Vreeland's paper[3]

Table 1—Copper Beryllium Alloys for Spot- and Seam-Welding Electrodes. Delmonte[49]

Cu	Be	Co	Cr	Zr	Si	Brinell Hardness	Electric Conductivity, % IACS	Tensile Strength, Lb./In.²	Elongation
97.0	0.4	2.6	...	...	...	200–220	50	90,000–115,000	10–15%
99.5	0.1	...	0.4	...	...	140	70–75	50,000–60,000	10–15%
99.2	0.3	...	...	0.5	...	...	82–85	40,000–67,000	.....
99.0	0.15	...	0.85	...	...	...	65–69	45,000–74,000	.....
96.5	0.4	2.6	...	...	0.5	...	55–58	100,000	.....

should be consulted by all who are interested in spot welding variables for copper alloys.

Spot-and seam-welding machines are described by a large number of writers of whom only a few can be cited. Hoch[38] describes portable welders of the gun, pincers and separate electrode types. Pincer and bar type welders (up to 100 kva., 2 sheets each 0.12 inch thick, 20 inches throat) are also described by Ten Geuzendam[39] who illustrates a parallel spot welder for motor coach fabrication whose upper electrodes[40] are suspended from the roof so that there is no throat limitation. By use of separate twin electrodes, Ross and Eckman[41] show how spot welds (75 kva.) can be made in mild steel 16 gage and lighter within a radius of 6 ft. from the ground electrode. Fixtures and machines for Hydromatic welding (spot welding electrodes actuated in succession by hydraulic cylinders) are illustrated by Roth.[42] Electrician[43] refers to the welding of wire mesh with a standard spot welder with wide electrodes. Cross wires are laid over and welded to 21 longitudinal wires at one operation.

The principle of electromagnetic storage to regulate peak current at a constant value is described in an English periodical.[44] The secondary current rises exponentially during the welding period. D.C. is said to be better than A.C. for spot welding; it has been found that 150 kva. may be needed to spot Duralumin 0.16 inch thick but only 30 kw., D.C. A decrease in electrode pressure during the welding period followed by an increase after current is switched off is desirable because the resistance is increased so that less current is required. The condenser discharge method is recommended by Popov[45] for portable spot welders for stainless steel aircraft repair. The outfit consists of a 10,000-volt transformer, and rectifier, and 6 condensers, each 24 mf.

The calculation of bus connections for resistance welding machines is explained in detail by Douglass and Clark.[46] Schlechter[47] presents some measurements of voltage variations in power mains arising from spot and seam welders for steel radiators.

Tips

According to *Sheet Metal Industries*,[48] general rules for spot-welding electrodes are: (1) it should not have a long tapered point; (2) high conductivity tips are necessary for scaled surfaces; (3) the tip should be rounded to 1 to $1^1/_2$ times the diameter of the shank; (4) mushrooming alters power and pressure settings and should not be allowed. Table 1 is due to Delmonte,[49] who states that plain $2^1/_2$% Be-Cu alloy is not suitable because it softens under the welding heat. The Cr-Cu alloy is an all-purpose electrode. The cobalt alloys are good for 18–8 but not for plain carbon steel. DiGiulio[50] mentions that cast copper alloy electrodes are good (no details) and that mushroomed tips create an uneven recrystallized zone in the weld. Wilson[37] states categorically that spot welding electrodes should make an angle of 15° with the surface of the sheets. Zimmerman[51] points out that as much as 60% of the electrode pressure may be relieved by the current surge through the secondary, to be returned with extra load by the elastic recoil of the machine following the surge.

Contrary to usual practice, Lapidus[52] found that it is unnecessary to de-scale sheet iron 0.012 to 0.08 inch thick before seam welding if the scale is 0.0004 to 0.004 inch thick. A few examples of spot welding in the manufacture of small electrical apparatus are cited by Kage,[53] including the spot welding of flattened copper wire to thin aluminum foil. Product Engineering[54] shows how to spot weld steel tubes to sheets in tubular construction using an indirect welder and flat electrode, or a two-electrode gun. Meadowcroft[55] discusses portable and frame jigs for spot and projection welding.

Projection Welding

Despite Miller's[56] statement that projection welding is not suited to non-ferrous metals and despite the lack of information on the method, projection welding is widely used for mass production. In projection welding the heat is localized by projections stamped into one of the two sheet metal parts to be joined, as Cooper[57] points out. He supplies Table 2 and gives 24 illustrations of typical projections. Fassler's[1] experience is that it requires about 15 kva. per spot in projection welding mild steel $^1/_8$ inch thick. Scaled metal may produce burnt projection welds by limiting the area of current conduction when the projection collapses, according to Wilson.[37]

Table 2—Projection Welding of Mild Steel. Cooper[57]

Stock Thickness	Height of Projection, Inch	Diameter of Projection, Inch
22 gage	0.035	$^1/_8$
$^3/_{16}$ inch	0.055	$^7/_{32}$
$^1/_2$ inch	0.063	$^9/_{16}$

Flash Welding

The theory of flash welding advanced by Kilger[58] on the basis of oscillograms and an examination of the surface of steel after cooling from the early stages of flash welding is that current bridges are established across the flashing surfaces. The material forming the bridges rapidly reaches the vaporization temperature and causes arcing. This theory is accepted by Rietsch[59] who gives a chart showing the loss of material during flash welding and describes an automatic flash welder in which the

parts are preheated by a series of short back and forth motions until flashing continues even with uniform forward motion. Upset occurs by increasing the rate of forward motion. It is this type of machine that Clapp[60] refers to as successful in welding rails on the South Australian Railways. Some details of flash welding practice for rails on the Delaware and Hudson Railroad are given by Ellson.[61] The process is performed continuously in a welding car from which the joints pass to a stress-relieving furnace. Closure welds are made by the Thermit process with insert.

Repeated impact and rotating bend fatigue tests on flash-welded mild steel 1.18 inches diameter, according to Kilger,[62] showed that the fatigue limit rises from 11,500 lb./in.^{2} at 1000 lb./in.^{2} push-up pressure to 27,000 lb./in.^{2} at 4600 lb./in.^{2} push-up pressure. The limit for hand operated machines is said to be 6.2 sq.in., in which case the operator must exert 65 lb. on the hand wheel to maintain a push-up pressure of 2800 lb./in.^{2} The flash welding of 18–8 is much the same as mild steel, according to Whitmer.[63] Taylor's[64] instructions for flash welding mild steel contain nothing new. Woofter[65] describes flash welders (60 to 200 kva.) for safe ending locomotive boiler tubes and superheater flues. The comparison of chain making processes made by Hogendoorn[66] showed that flash welded chain had 75 to 85% of the strength of the unwelded steel (tensile strengths ranged from 68,000 lb./in.^{2} to 85,000 lb./in.^{2}); welds made by several other processes had 70 to 82%. MacFarland[73] states that an atmosphere of neutral gas is advantageous in avoiding burning in flash welding.

Resistance Butt Welding

A historical review by Ebert[67] of German resistance butt welding processes for chains concludes with the statement that fully automatic machines now weld chain stock to $^1/_2$ inch diameter. The continuous resistance seam welding of pipe up to $3^7/_8$ inches diameter, 18 to 6 gage (the lighter gages only up to $2^1/_4$ inches diameter) between two revolving water-cooled copper electrodes is described by Electrical Times.[68] Several thousand amperes, 2 to 3 volts, single phase, is used and the speed is 25 to 110 ft./min. Herb[69] refers to the same process, in which the edges are pressed together as current is applied (no details), and *Product Engineering*[70] supplies Table 3 for resistance seam-welded tubing $^3/_{16}$ to 5 inches outside diameter made with the roller electrodes. Meebold[71] describes a resistance butt welding machine for steel wire and discusses the question of cooling rate. Quenched and drawn S.A.E. 1040 forgings for the Ford front radius

Table 3—Mechanical Properties of Welded Tubing[73] (Seams Welded by the Resistance Butt Process)

Steel	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation % in 2 Inches	B Rockwell Hardness
S.A.E. 1010 (medium)	45,000	55,000	25	60
0.10 C, 1.0–1.4 Mn	60,000	75,000	15	95
18–8	45,000	90,000	35	90

rod are resistance butt welded, to the slow cooling after which is due the large grain size, according to DiGiulio.[50] Kuhn[72] summarizes the report of an English Insurance Company on failures in austenitic chromium-nickel steel (containing 0.5% *W*) superheater tubes which were resistance welded to short lengths of mild steel tubing 2 inches outside diameter, 0.18-inch wall. Cracks containing Na_2CO_3 with traces of NaOH occurred in the austenitic steel close to the weld but were not intercrystalline. It was conjectured that the main cause of the cracks lay in corrosion fatigue caused by the excessive bending stresses created, in turn, by the difference in thermal conductivity between mild and austenitic steel. Cracks also tended to occur in the oxidized material pressed out during welding but these were not associated with the main cracks.

Percussive butt welds in rods $^1/_2$ inch diameter of almost any alloy, e.g. chromium steel to phosphor bronze may be made in 0.01 sec. with 30,000 amp. and $^1/_{16}$-inch arc, according to MacFarland.[73] Bibber and Gammeter[74] apply the term "conductive melt process" to the resistance welding method in which a heavy flux supplies heat for melting a bare electrode in the automatic butt welding of plates several inches thick in a single pass.

REFERENCES (RESISTANCE WELDING)

1. Fassler, P. W., *Sheet Metal Inds.*, **11** (125) 834–835, (126) 929–931 Sept., Oct. 1937.
2. La Cour, I. L., and Faye-Hansen, K., *Die Transformatoren;* Springer, Berlin, Third Edn., 552 (1936).
3. Crampton, D. K., and Vreeland, J. J., American Welding Society Journal, **16** (10) Research Suppl., 9–18, Oct. 1937.
4. Kislyuk, F. I., *Avtog. Delo*, **8** (8) 15–21; (9) 4–11, Aug., Sept. 1937.
5. Roulleau, J., *Ann. de Physique*, Series 11, **8**, 153–236, Sept. 1937.
6. Van Thijn, H. E., *SAE Jnl.*, (Trans.) **40** (3) 108, March 1937.
7. Frost, L. H., *Welding Engr.*, **22** (6) 32–33, June 1937; *Elect. Engg.*, **56** (7) 865–866, July 1937.
8. Mathieu, M., *Rev. Gen. Elect.*, **41**, 293–297, March 6, 1937; *Bull. Soc. Franc. Electriciens*, Series 5, **7** (78) 665–672, June 1937.
9. Whitmer, V. W., American Welding Society Journal, **16** (9) 16–18, Sept. 1937.
10. Mikhalopov, G. S., *ibid.*, **16** (10) 59–61, Oct. 1937.
11. Thomasson, H., *Engg. Jnl.* Canada, **20** (1) 8–14, Jan. 1937.
12. Anon., *La Metallurgie*, Special number of Paris Fair, 33–39, May 1937.
13. Landstrom, H., American Welding Society Journal, **16** (10) 12–14, Oct. 1937.
14. Wilbert, H., *Siemens Zeit.*, **17** (2) 74–78, Feb. 1937; *Elektroschw.*, **8** (10) 190–191, Oct. 1937.
15. Henney, K., *Electron Tubes in Industry*, McGraw-Hill Book Co., N. Y., Second Edn., 253–266 (1937).
16. Palmer, H. L., *G. E. Rev.*, **40** (5) 229–235; (7) 321–325, May, July 1937.
17. Hutchins, W. C., American Welding Society Journal, **16** (8) 11–18, Aug. 1937; *G. E. Rev.*, **40** (3) 116–124, March 1937.
18. Schilling, W., *Arch. Elektrotechn.*, **31** (4) 213–232, April 22, 1937.
19. Pelton, R. S., *Metal Progress*, **32** (1) 59–62, July 1937.
20. Taguti-Kisaburo, *Shibaura Review*, **16** (6) 225–230, June 1937.
21. Anon., *L'Electricien*, **53**, Second Series, 155, April 1, 1937.
22. Anon., *Welding Ind.*, **5** (8) 266–267, Sept. 1937.
23. Hall, J. G., *Welding Ind.*, **5** (9) 313–314, Oct. 1937.
24. Packard, D., and Hutchings, J. H., *Elect. Engg.*, **56** (1) 37–40, **66** (7) 875–877 (1937); *G. E. Rev.*, **40** (2) 93–97, Feb. 1937.
25. Vedder, E. H., and Dawson, J. W., *Iron Age*, **140** (19) 28–33, 81–82 (21) 44–49, Nov. 1937.
26. See reference 15, page 477.
27. Anon., *Welding Ind.*, **5** (3) 83–84, April 1937.
28. Bodlander, R., *Modern Engr.*, **11** (6) 328–333, June 1937.
29. Gray, T. S., and Nottingham, W. B., *Rev. Sci. Inst.*, **8** (2) 65–68, Feb. 1937.
30. Sidorenko, A. M., *Thyratron Control, Bull. Electric Welding Inst.*, Kiev, Russia, 49 pages (1937).
31. Craig, P. H., *Electronics*, **10** (9) 26–28, Sept. 1937.
32. Stansbury, C., *Elect. Engg.*, **56** (5) 583–588, May 1937.
33. Roby, F. H., *Elect. Engg.*, **56** (9) 1145–1148, Sept. 1937.
34. Barbour, W., *Mill & Factory*, **20** (3) 66–68, March 1937.
35. Thomasson, H., *Canadian Machinery*, **48** (5) 50–51, May 1937; American Welding Society Journal, **16** (7) 26, July 1937.
36. Hensel, F. R., *Iron & Coal Trades Rev.*, **135** (3635) 706–707, Oct. 29, 1937; *Ind. & Weld.*, **10** (11) 43–46, Nov. 1937.
37. Wilson, L. B., *Welding Ind.*, **5** (8) 297–301, Sept. 1937.
38. Hoch, F., *Elektroschwg.*, **8** (2) 21–27, Feb. 1937.
39. Ten Geuzendam, K. F., *Laschtechniek*, **3** (4) 44–45, April 1937.
40. Ten Geuzendam, K. F., *ibid.*, **3** (11) 131–134, Nov. 1937.
41. Ross, E. F., *Steel*, **100**, 36–38, 72, April 5, 1937; Eckman, M. L., American Welding Society Journal, **16** (8) 19–20, Aug. 1937.
42. Roth, H. W., *American Machinist*, **81** (1) 17–21, Jan. 13, 1937.
43. Anon., *Electrician*, **118**, 136–137, Jan. 29, 1937; *Sheet Metal Inds.*, **11** (117) 63–64, Jan. 1937.
44. Anon., *Machinery* (London) **50** (1285) 257–259, May 27, 1937.
45. Popov, S. M., *Avtiopromishlennost*, **6** (3) 61–64 (1937); *Avtog. Delo*, **8** (8) 21–25, Aug. 1937.
46. Douglass, A. S., and Clark, L. W., American Welding Society Journal, **16** (10) 64–70, Oct. 1937.
47. Schlechter, H., *Elektrowärme* (9) 192–194 (1937).
48. Anon., *Sheet Metal Inds.*, **11** (121) 479, May 1937.
49. Delmonte, J., *Weld. Engr.*, **22** (4) 33–34, April 1937.
50. DiGiulio, A., American Welding Society Journal, **16** (3) 8–14, March 1937.
51. Zimmerman, J. H., *Elect. Engg.*, **56** (7) 866, July 1937.
52. Lapidus, V. A., *Avtog. Delo*, **8** (8) 29–31, Aug. 1937.
53. Kage, H., *Maschinenbau*, **16** (11/12) 301–302, June 1937.
54. Anon., *Product Engg.*, **8** (10) 396–398, Oct. 1937.
55. Meadowcroft, J. W., American Welding Society Journal, **16** (4) 11–13, April 1937.

56. Miller, J. L., *Coventry Engg. Soc. Jnl.*, **18** (3) 68–90 (1937).
57. Cooper, J. M., *Product Engg.*, **8** (9) 334–336, 360–361, Sept. 1937.
58. Kilger, H., *Elektroschweissung*, **8** (1) 4–8, Jan. 1937.
59. Rietsch, E., *Maschinenbau*, **16** (1/2) 25–28, Jan. 1937; AMERICAN WELDING SOCIETY JOURNAL, **16** (7) Research Suppl., 7–9, July 1937.
60. Clapp, H. W., *Broken Hill Prop. Review*, **14** (5) 6–7, Aug. 1937.
61. Ellson, G., *Bull. Intnl. Rwy. Cong. Assn.*, **19** (1) 2–6; 18–27, Jan. 1937; see also Anon., *Rwy. Age*, **103** (10) 300–302, 310–311, Sept. 4, 1937; *Rwy. Engg. & Maintenance*, 596–600, 612, Sept. 1937; *Steel*, **101** (18) 52–53, Nov. 11, 1937; *Construction Methods*, **19**, (11) 45–47, Nov. 1937.
62. Kilger, H., *Siemens Zeit.*, **17** (1) 8–12, Jan. 1937.
63. Whitmer, V. W., AMERICAN WELDING SOCIETY JOURNAL, **16** (9) 18–19, Sept. 1937.
64. Taylor, A. E., *Product Engg.*, **8** (10) 399–401, Oct. 1937.
65. Woofter, H. A., AMERICAN WELDING SOCIETY JOURNAL, **16** (9) 24–27, Sept. 1937.
66. Hogendoorn, W. M., *Polytechnisch Weekblad*, **31** (1) 24–26, Jan. 1937.
67. Ebert, W., *Maschinenbau*, **16** (15/16) 413–415, Aug. 1937.
68. Anon., *Electrical Times*, **91**, 515–516, April 15, 1937.
69. Herb, C. O., *Machinery* (N. Y.), **44** (1) 1–5 (1937).
70. Anon., *Product Engg.*, **8** (8) 302–304, Aug. 1937.
71. Meebold, —, *Draht-Welt*, **30** (26) 316–318 (1937).
72. Kuhn, E., *Wärme*, **60** (31) 485–488, July 31, 1937.
73. MacFarland, A. M., *Weld. Engr.*, **22** (6) 32–33, June 1937.
74. Bibber, L. C., and Gammeter, E., *Met. Prog.*, **32** (4) 551–553, 557–558, 560, Oct. 1937.

APPENDIX II

Welding Non-Ferrous Metals

(Other Than Copper and Aluminum)

Nickel and Its Alloys

Monel metal is the most important nickel alloy from the standpoint of welding. A paper presented at the 1937 Metal Congress by F. G. Flocke on the Arc Welding of Monel Metal summarizes recent research on mechanical properties and procedure. Jennings[1] finds that coated Monel rods must be used for both metal arc and carbon arc welding. The Monel electrode (reversed polarity) is wrapped with aluminum wire to serve as deoxidizer and to avoid porosity. It is used for sheet from 24 gage up. Carbon arc is best for 16 to 24 gage. Metal arc is faster than carbon arc and produces more ductile welds. Welds in *K* Monel have a tensile strength of 90,000 to 95,000 lb./in.^{2}, 40 to 45% elongation in 2 inches after being stress relieved 3 hr. at 1077° F. On account of fluidity, flat welding is necessary, Maguire[2] states, for arc welding Monel plate 1/2 inch thick, X welds. By choking the arc at the end of a bead and allowing the crater to fill up, crater cracks are prevented. Sitler[3] describes a steel wedge for maintaining correct spacing in long welds in Monel sheet. A French magazine[4] describes a welded Monel pickling tank, and Müller[5] gives details of an arc-welded washer for NaCl liquor at 150° C. which is 150 feet long made from thick Monel plate. Not a single rivet was used and stainless steel corroded badly in the brine.

According to Jennings,[1] the arc welding of nickel is similar to that of Monel. A 70° V is used in butt welding nickel to steel. A thin layer of nickel is deposited on the steel kerf before the weld is made with nickel electrodes. Nickel has excellent spot welding characteristics, according to Wise,[6] and spot welds readily to molybdenum or Dumet lead-in wires for vacuum tubes. The electric resistance of nickel is sufficient to develop adequate heat without excessive electrode wear. Since nickel forms no carbides, welds to carbonized nickel surfaces are tough. Hignett[7] found that care must be exercised to prevent gas holes in oxyacetylene welds because nickel has a high solubility for hydrogen, and, it might be added, for CO as well. Oxygen is the troublesome gas, according to Nishimura.[8] Arc welds made with covered electrodes contained 0.3 to 0.48% oxygen which embrittles the weld. Arc welds made in an atmosphere of illuminating gas or CO_2 were tough.

Oxyacetylene welds in Inconel, Boutté[9] states, should be made with flux (no details) and the plates are prepared in the same way as in welding Monel, both of which are hot short at 800° C. To weld the corners of Inconel or Monel photographic basins, *Sheet Metal Worker*[10] recommends the use of silver ribbon 3/8 inch wide, 0.005 inch thick, which is folded into double seams at the corners and melted to form a tight joint by means of an air-acetylene torch. An X-ray diffraction and metallographic study of welds in high carbon 65 Ni—15 Cr heat resisting alloy by Ziegler and Haughwout[11] showed that the grain size of the as-cast material was larger than that of the low-carbon weld metal, which, in turn, was larger than that of castings that had had several thousand hours use. Polarized light is required to measure grain size correctly by metallographic means if carbide envelopes are present.

Magnesium and Its Alloys

Magnesium welding is attracting considerable attention in Germany. A few extracts from Bungardt's[12] statement of the present position of magnesium alloys may not be amiss, although in most repects he agrees entirely with Menking (*Metals Handbook*, 1936 edition, 1225–1228). Welding characteristics improve as the range between liquidus and solidus is decreased. If hammered, welds in the 6% Al alloy will crack. Castings can be burnt on by preheating to 300° C. Winkler[13] and Łoskiewicz[17] also outline the usual procedure for oxyacetylene welding and Winkler adds that the flame should be reducing and green in color. Seam welds in Electron are as smooth as in aluminum alloys, according to Rosenberg.[14] The average breaking load for 0.14 inch diam. spots in 0.036-inch sheet was 265 lb. per spot. The corrosion resistant coating customarily applied to magnesium alloys must be removed before spot or seam welding. Atomic hydrogen welds[15] can be made in Electron without danger of fire. Eyles[16] emphasizes the importance of hammering at 550° F. to close porosity and refine the coarse grained heat-affected zone. Unhammered oxyacetylene welds in rolled Electron have only 40 to 60% of the strength of base metal (weld at right angles to load) whereas hammered welds have 75 to 90%. The oxyhydrogen flame is useful only for very thin sheet and sections. All welds in magnesium and its alloys should be annealed. Mc Carroll[18] mentions the use of spot and oxyacetylene welded dowmetal in the construction of sleeper busses.

Lead

Instructions for welding lead have been prepared by the French Gas Welding Institute,[19] a German magazine[20] and Peters.[21] Peters stresses the importance of rapid welding on account of the low melting point and low heat conductivity of lead. A neutral or slightly reducing oxyacetylene flame should be applied perpendicular to the surface of the sheet. Hiers[22] describes the batten system for applying lead linings. The oxyhydrogen flame seems to be preferred Peening breaks down the crystal structure. Dixon[23] found that the batten system (half oval steel washers secured by countersunk plow bolts over which strips of lead are placed and welded into the lining proper) is inadequate to resist the stresses set up by cycles of heating and cooling. Cracks occurred in the welds at the battens. Battens are now being replaced by lead rivets. A detailed description is given by *Sheet Metal Worker*[24] of the welding of antimonial sheet lead ducts 1/16 to 3/32 inch thick.

Zinc

A good deal of the mystery about zinc welding is dispelled by Burkhardt.[25] To weld zinc it is unnecessary to nickel plate it, nor is excess oxygen desirable. Use a small oxyacetylene torch, grooved carbon plates as backing strips, 90° V with 0.08 to 0.12 inch space, and a rod of the same analysis as, and one-third the thickness of, the plate. Flux is not essential but pastes of lithium salts are good. Rod is held between torch and weld, and is puddled. Welds in alloy containing 4% Al, 0.5% Cu, 0.03% Mg had a tensile strength of 35,000 to 38,000 lb./in.^{2} as-welded, and 53,000 to 57,000 lb./in.^{2} cold hammered. The weld must have had practically the same strength as base metal. Arc welding must be done very rapidly to avoid burning through. Spot welds in sheet less than 0.08 inch thick are good. Forge welding may be done if no aluminum is present by hammering at 350° C. Soldering is not recommended (especially tin soldering which leads to intercrystalline corrosion), but a solder containing 70% Cd, 14% Zn, 10% Sn, 6% Pb may be used with soda as flux. The strength is 12,000 to 15,000 lb./in.^{2}

Burkhardt's effort to clear up the mystery in zinc welding has been undone to some extent by Anders,[26] who claims great things for oxyacetylene welds made with a "certain" flux. Without information on the flux his paper is worthless, although he does disclose that the air-acetylene flame is useless for zinc and annealing at 140 to 150° C. is valuable for grain refinement. Another element of mystery has been introduced into the situation by McClain,[27] who found rows of blow-holes in the mushy zone of welds in zinc-base die castings. The oxide on the surface was Al_2O_3. It is claimed[28] that the "Alladin" rod for zinc base die castings produces good welds. A seam welder for zinc battery cases is described in a German magazine.[29]

Gold

A review on the soldering of gold and other precious metals has been prepared by Bihlmaier.[30] In the 1937 edition of their textbook on gold, Rose and Newman[31] list a number of gold solders containing 20 to 87.5% Au with up to 40% Ag, up to 28% Zn, up to 11.5% Cd or up to 3% Zn. The solidification temperatures range between 724 and 900° C. Barham and Jones[32] observed that crystal growth occurred across the interface of two gold specimens, previously polished, etched, annealed and pressed together under 6700 lb./in.^{2} when heated to 800° C. for 10 minutes. If the specimens were not etched after being polished, no grain growth occurred, presumably owing to the interference of a film of polishing agent: MgO. Thus, intercrystalline cement does not appear to be necessary for crystal growth but intercrystalline films hinder growth.

Silver

As Folgner[33] explains in detail, silver solders are of two types: (*a*) 80% Cu, 15% Ag, 5% P, which melts at 1185° F. and is free flowing at 1300° F.; (*b*) 50% Ag, 15½% Cu, 16½% Zn, 18% Cd, which is patented, starts to melt at 1160° F. and is free flowing at 1175–1200° F. The requisite low-temperature flux is based on potassium fluoride and is extremely fluid without bubbles at 1200° F. A soft flame should be used. Without providing details, Crampton[34] states that methods have been developed for welding iron or copper coated with a heavy layer of silver.

REFERENCES (WELDING NICKEL, MAGNESIUM, ETC.)

1. Jennings, C. H., *Iron Age*, **139**, 44–47, Feb. 11, 1937.
2. Maguire, J. F., American Welding Society Journal, **16** (7) Research Suppl., 4–7, July 1937.
3. Sitler, W. F., American Welding Society Journal, **16** (4) 6, April 1937.
4. Anon, *Rev. Nickel*, **144**, Sept. 1937.
5. Muller, R., *Chem. Apparatur*, **24** (18) 300–301, Sept. 25, 1937.
6. Wise, E. M., *Proc. Inst. Radio Engrs.*, **25** (6) 723, June 1937.
7. Hignett, H. W. G., *Metal Ind.* (London), **50**, 129–136, Jan. 22, 1937.
8. Nishimura, H., *Japan Nickel Review*, **5** (2) 158–171, April 1937.
9. Boutté, A., *Soud-Coup.*, **12** (1) Jan. 1937; *Schweiss. u. Schneidbrenner*, **16** (1) Jan. 1937.
10. Anon, *Sheet Metal Worker*, **28** (6) 25–27, 56, June 1937.
11. Ziegler, F. K., and Haughwout, L. B., *Metals & Alloys*, **8** (8) 225–229, Aug. 1937.
12. Bungardt, K., *Z. VDI*, **81** (45) 1289–1293, Nov. 6, 1937.
13. Winkler, C., *Werkstatt u. Betrieb*, **70** (7/8) 90–91, April 1937.
14. Rosenberg, F., *Aluminium*, **19** (2) 89–97, Feb. 1937.
15. Rosenberg, F., *Aluminium*, **19** (4) 260, April 1937.
16. Eyles, A. J. T., *Industrial Gases*, **18** (1) 43–45, March 1937.
17. Łoskiewicz, W., *Przeglad Mechaniczny*, **3** (9) 325–334, May 10, 1937.
18. Mc Carroll, G., *Automotive Inds.*, **76**, 689, May 8, 1937.
19. *La Soudure Autogène Oxyacétylenique du Plomb;* Office Central de l'Acetylene et de la Soudure Autogène, 47 pages, Paris, 1937.
20. Anon, *Illust. Zeit. Blechindustrie*, **66** (10) 297–298; (11) 323–324 (1937).
21. Peters, A. E., *American Machinist* (European Edn.), **81** (25) 362 *E* (1937).
22. Hiers, G. O., *Refiner*, **16** (4) 168–172, April 1937.
23. Dixon, E. S., *Refiner*, **16** (10) 464–465, Oct. 1937.
24. Anon, *Sheet Metal Worker*, **28** (9) 23–24, Sept. 1937.
25. Burkhardt, A., *Technologie der Zinklegierungen*, Springer, Berlin, 232–234 (1937).
26. Anders, W., *Autog. Metallb.*, **30** (3) 33–36, Feb. 1, 1937; see also Keel, C. F., *Zeit. Schweisstechnik*, **27** (6) 117–119, June 1937; and Anon, *Autogenschw.*, **10** (4) 49–50, April 1937.
27. McClain, —, *Metal Ind.* (London), **50**, 299–300, Mar. 5, 1937.
28. Anon, *Machinery* (N. Y.), **43**, 477, March 1937.
29. Anon, *Werkstatt u. Betrief*, **70** (3/4) 38, Feb. 1937.
30. Bihlmaier, K., *Mitt. Forsch.-Inst. Probieramt Edelmetalle Staatl. Höhere Fachschule, Schwab. Gmund*, **10**, 108–113, Jan.–Feb. 1937; see also earlier issues **9**, 85–90, 99–106, Jan. 1936; **10**, 68–72; 84–86, Aug.–Sept. 1936.
31. Rose, Sir T. K., and Newman, W. A. C., *The Metallurgy of Gold*, J. B. Lippincott, Philadelphia, page 55, 1937.
32. Barham, B. S., and Jones, W. D., *Metal Ind.* (London), **50** (6) 181–182 (1937).
33. Folgner, H. A., *Metals & Alloys*, **8** (1) 29–32, Jan. 1937.
34. Crampton, D. K., *Metal Progress*, **32** (4) 574, Oct. 1937.

APPENDIX III

Aluminum Welding

The striking thing about all the recent development and research in the welding of aluminum and its alloys, according to Hignett,[1] is the serious loss in mechanical properties of welds in any of the heat-treated aluminum alloys except the Mg_2Si alloys. Consequently, not much advance has been made in the fusion welding of aluminum alloys, although fusion welds in a wide range of thicknesses of commercial aluminum may now be produced with proper technique. Evidence of the reliability of fusion welded aluminum has been given by the Committee on Tank Cars of the AAR,[2] who now permit calk welding of riveted aluminum tanks on tank cars. To prevent overheating the bead should not penetrate more than $^3/_{16}$ inch. Of all the welding processes for aluminum and its alloys the resistance spot and seam processes have undergone the greatest development.

Spot and Seam Welding

Present practice in spot and seam welding is described by Hoglund.[3] The processes are applicable to thicknesses less than $^3/_{16}$ inch. Except for 2*S* and 3*S*, the oxide coating that forms in air must be removed from the area under the electrodes or sometimes on both sides of each sheet by means of etching in a solution of *HF*, gum tragacynth, alcohol and water, or wire brushing. No copper alloy with an electric conductivity less than 75% that of pure copper is suitable for tips. Water cooling should be carried to within $^3/_8$ inch of the contact surface, and the contour of this surface on at least one of the electrodes should be a flat cone of 7° angle. Tips make 250 to 400 spots before remachining. Best strength, toughness and

corrosion resistance is obtained if the weld extends $^2/_3$ of the distance to the surface, in which case a bubble at the interface is unavoidable. The distance between the edges of successive spots should be at least four times the sheet thickness to avoid poor fusion due to shunt effect. The breaking load varies almost linearly with sheet thickness for Alclad 24 *St* and 52 $S^1/_2H$ (for the latter 130 lb. at 0.020 inch thick, 1700 lb. at 0.125 inch thick).

Spot- and seam-welded aluminum aircraft tanks (2*S* and 3*S*) are designed on the basis of vibration fatigue tests as Hartman[4] describes. A tank may carry 1700-lb. fuel, and weigh 0.4 lb./gal. (0.064-inch sheet). The common spacing of spot welds is $^3/_4$ to 1 inch, but should not be less than $^5/_8$ inch. The distance from center of spot to edge of sheet should be at least four times the sheet thickness. In spot welding sheets of different thicknesses, a difference of 1 or 2 B & S numbers is not significant.

The open circuit secondary voltage of spot welders for aluminum alloys (25,000 amp.), according to Bohn,[5] may vary from 5 volts for short throat and small vertical distance between arms to 15 volts for long throat and arm distance. Redressing in a lathe is preferable to filing for tips. On account of the shunt effect the current for seam welding is 25% greater than for spot welding. Tentative data for spot welding are given in Table 1.

Table 1—Tentative Spot Welding Data for Aluminum Alloys. Bohn[5]

(Some variations may be required for different alloys)

Thickness, Inch	Number of Cycles	Current Amperes	Tip Pressure, Lb. Minimum	Maximum
0.016	4	14,000	200	400
0.032	8	18,000	400	600
0.064	10	24,000	500	700
0.128	15	35,000	800	1200

Recent German Research on spot-welded Alclad and Hydronalium (effect of machine factors, and of "program" control of current and pressure to give forging action on solid weld) is described by Osswald.[6] Electrolytic copper tips, slightly hemispherical for movable electrode and flat for the fixed electrode, are preferred. The pulsating tension fatigue strength of Alclad is much higher than that of spot-welded hydronalium 7 of the same thickness (285 lb. per spot in Alclad 0.078 inch thick, 1 million cycles). Solidification shrinkage cavities cannot be avoided in thick sheet (0.078 inch) if high strength is desired, but Schober[7] believes bubbles can be avoided with tube control.

Additional German research is reported by Rosenberg,[10] who deals with spot welds in aluminum, Pantal (0.5–1.0 Mg, 0.4–1.4 Mn, 0.8–2 Si, 0.3 Ti), Bondur (3.5–5.5 Cu, 0.2–2 Mg, 0.2–1.5 Si, 0.1–1.5 Mn) and other alloys from 0.016 to 0.079 inch thick. As the current is raised the breaking load increases almost linearly for commercial Al 12,500 amp. gives 88 lb. (but 11,400 lb./in.^{2}, 0.039 inch thick) whereas 25,000 amp. gives 350 lb. (but 8500 lb./in.^{2}) for single spots. Increasing the time at 12,500 amp. from 1 to 8 cycles had practically no effect on breaking load. An increase in electrode pressure on Bondur (0.039 inch thick, 25,000 amp., 10 cycles) from 190 to 730 lb. lowered the breaking load per spot from 650 to 325 lb. In seam welding Bondur as the distance between spots increases, the breaking load increases but the breaking stress decreases. An increase in speed of seam welding Duralumin, 0.039 inch thick, from 21 to 30 inches/min. increased the breaking stress slightly from 42,500 to 45,000 lb./in.^{2} Further increase in speed to 60 inches/min. lowered the breaking stress to 24,000 lb./in.^{2} Power consumption for spot welds in two sheets 0.039 inch thick is:

4.8 kw-sec per spot for commercial aluminum
12 " " " " Pantal
16 " " " " Bondur

Power consumption for seam welds can be computed directly from data for single spots. Heat treatment of spot welds in Bondur increased the breaking load from 3 to 43%. The lower the as-welded strength, the greater is the effect of heat treatment (water quench 400° C.).

The percentage of time during which power is applied in seam welding aluminum alloys should not exceed 25%, according to Blank.[8] For instance, a wheel speed of $3^1/_2$ inches/min. was used for a common Al alloy (0.064 inch thick) with 2 cycles on, 7 cycles off with excellent results, the fatigue strength (no data) being comparable with that of riveted joints.

Burns[9] has prepared a single chart for 17 *St* showing the relation between sheet thickness, time, weld diameter, electrode pressure and welding current. A general purpose single spot machine with electronic timer for medium gage aluminum alloy may cost $4000 to $5000. Burns conceives of the spot welding of aluminum alloy in the early stages as extremely local fusion at small points in contact. He does not explain the usual spot welding instructions for cleanliness and smoothness of surface on the basis of his theory.

The discussion of spot welding given by Eyles[11] agrees very closely with practice in this country. The spot welding of a Russian alloy, Altmag (5–8% Mg, 0.5–1 Mn, 0.1–0.5 Ti), is described by Orlov.[12] Up to 0.118 inch total thickness can be handled by copper electrodes in which case the electrode should be 0.16 inch diameter, the duration of welding 0.20 sec., and the pressure 40 to 95 lb. The breaking stress per spot is only 20,500 to 26,000 lb./in.^{2} Suhr[13] points out that spot welding is the only process in general use in Germany for structural-aluminum. A micro-Vickers diamond pyramid hardness tester is used by Lips[14] to show the variation in hardness across a spot weld in heat-treated duralumin. He concluded that a good spot weld should have the same hardness as the surface of the sheet and that the heat-affected zone should have somewhat higher hardness. Wilson[15] is very doubtful whether anything like a good spot weld can be made between a sheet of aluminum and a sheet of duralumin.

Gas Welding

A good deal of research has been done recently by German investigators[20] on the oxyacetylene welding of aluminum and its alloys. Buchholz used the two-torch vertical method in commercial aluminum plate 1 inch thick and found, on the basis of X-ray and metallographic examination, physical properties and corrosion tests, that the best filler metal is commercial aluminum itself, with or without 0.2% Ti. Filler rods containing 5% Si are not acceptable. Maier was unable to obtain nearly as high strength in oxyacetylene welds as in unwelded plate (0.16 inch thick) in soft and hard K.S. Seewasser (2.2 Mg. 1.3 Mn, 0.7 Si, 0.2 Sb). In Rajakovic's tests[21] on 7 oxyacetylene welded alloys, flange welding (without filler rod) gave higher strength than butt welding with filler rod only in those alloys whose age hardened condition did not give rise to small cracks on bending the flanges. Cautious cold hammering of heat-treated alloy welds can accomplish quite a bit in increasing the strength. To improve the corrosion re-

sistance of welds in heat-treated alloys they should be sprayed to a thickness of 5 to 8% of sheet thickness with Al-Mg-Si wire.

Zimmermann's[22] results on oxyacetylene welded commercial aluminum (99.5% Al 0.20 to 0.78 inch thick, cold rolled) are particularly informative. The welds have the same strength as soft annealed plate. Cold and hot hammering raised the strength a few per cent. V butt welds in 0.39 and 0.78-inch plate had 50 to 60% of the notch-impact value of base metal (specimens not completely broken). Cold hammering raised the notch-impact value 20 to 90% above that of the unhammered weld and hot hammered welds have the same notch-impact value as base metal. Rods containing titanium produce fine grained weld metal, but hot hammering decreases the grain size in the heat-affected zone as well. The V butt joint is the best for welded aluminum tubing or pipe. The corrosion resistance of welded commercial aluminum is improved by using a rod containing 0.2% Ti, hot hammering giving better corrosion resistance than cold hammering, according to Bollenrath and Gröber.[23]

Grahl[24] states that commercial aluminum and the Seewasser alloys (*KS* = 1.3 Mn, 2.2 Mg, 0.2 Sb, 0.7 Si; *BS* = 7.5 Mg, 0.3 Mn) should be gas welded with a flux and a rod of the same composition as base metal. Pantal (0.5–1.0 Mg, 0.4–1.4 Mn, 0.8–2 Si, 0.3 Ti) requires a 4–5% Si rod to avoid cracks. Sixt[25] recommends the 5% Si rod for oxyacetylene welding anything containing over about 85% Al (some welders in this country also regard the 5% Si rod (neutral flame and flux) as a cure-all), preheating being necessary for parts over $^3/_8$ inch thick.[29] In the face of much evidence to the contrary, Chevillotte[26] maintains that oxyhydrogen welds are better than oxyacetylene and hammer welds are better than both for welded tanks for hot conc. HNO_3. Thick welds in aluminum should be cold hammered and reheated to 350–400° C. with the blow pipe several times. Herenguel[27] outlines the procedure for oxyacetylene welding aluminum alloys containing magnesium, and Harada[28] supplies information on the welding of aluminum containing residual sodium.

Table 2—Mechanical Properties of All-Weld-Metal Deposited by Four Aluminum Rods.[33]

Rod	Pure Aluminum	5% Si	10% Si	5% Cu
Yield strength, lb./in.²	3600	8,300	12,800	13,000
Tensile strength, lb./in.²	9200	16,500	19,900	13,900
Elongation in 2 inches, %	38.0	7	6	1
Brinell hardness	13.7	37.6	46.8	80.0
Izod-Impact value, ft.-lb.	12.8	2.7	1.6	1.2
Purpose	sheet Al	castings and pure Al	castings	5% Cu castings

The design of oxyacetylene welded tanks of 99.6% Al for palm oil (18,000 cu. ft. capacity) is described in a Swiss welding magazine.[30] The tanks were 36 feet high, 9.3 feet diameter, 0.20 to 0.67 inch wall. Extensometer measurements made on one of the tanks filled with water revealed a maximum fiber stress of 4000 lb./in.² at 6° C. Some of the welding torches were made of aluminum to avoid fatigue of the welder. Schmitt[31] recommends the two-torch vertical method for the oxyacetylene welding of aluminum tanks. Instead of using cast flanges for pressed aluminum pots, flanges can be built up satisfactorily by oxyacetylene welding. Details of the mass production of oxyacetylene welded aluminum chairs are given by Jones.[32] The British Oxygen Company[33] recommend the two-torch vertical method with neutral flame for aluminum over $^1/_4$ inch thick. The mechanical properties of all-weld-metal deposited by their oxyacetylene rods are given in Table 2.

A detailed description of the welding of aluminum castings is given by Buckley.[34] Crank cases must be boiled in soda solution to get rid of grease. Neutral or slightly reducing flame is necessary, and the liquid metal is puddled. After 2 inches of weld have been made, play the torch lightly on the weld and smooth it over when it is plastic. Defective castings in as-cast silumin (10–13.5 Si), according to Reininger,[35] may be repaired without flux by means of a rod of the same composition. The blue cone (reducing zone) of the flame should not dip into the metal, and the bath should not be stirred, otherwise there is excessive oxidation. The repaired casting must be annealed at 300–350° C. at least 4 hr. to remove welding strains. Reininger gives a long discussion of 30 references to the welding of silumin. On account of rapid cooling the weld metal has higher strength and ductility than base metal. In another article on the welding of silumin castings, Reininger[36] states that the oxyhydrogen process is not suited to the welding of silumin castings on account of porosity. Two-jet oxyacetylene torches (one jet for preheating) are used with a rod containing 4 to 5% Si, flux being unnecessary. Special precautions (no details) must be taken in the welding of heat-treated silumin castings.

Although the weld metal deposited in arc welding silumin automotive castings may have a tensile strength of 24,000 to 37,000 lb./in.² according to Stieler,[42] the joint will generally have a strength of only 17,000 to 27,000 lb./in.², on account of blow-holes due to the impossibility of removing the last traces of oil. Well modified silumin requires no preheat for arc welding but poorly modified silumin should be preheated to 200–300° C. Silumin electrodes (D.C., electrode positive) of the same diameter as plate thickness should be used, but not over 0.32 inch. Peening is not required.

The fluxes used for welding aluminum alloy castings automatically modify aluminum-silicon alloys, according to Hignett,[37] who also found that if silumin castings must be welded to aluminum, the silumin must be degassed in order to prevent porosity in the weld. The grain is coarser in weld than in casting, but the strength is the same. Hignett emphasizes the importance of using the correct flux for welding aluminum, which according to the British Oxygen Company[33] is usually composed of chlorides and fluorides of lithium, sodium and potassium. Holder[38] mentions an aluminum welding flux composed of alkali halides and an acid sulfate. A review of patented fluxes for welding and soldering aluminum has been made by Nischk.[39]

Atomic Hydrogen Welding

Atomic hydrogen welding has many advantages for welding aluminum and its alloys, as the extensive tests made by Rajakovics[21] can testify. The method is applicable to sheet as thin as 0.012 inch, and produced welds in the Al-Mg and Al-Cu-Mg alloys (0.039 inch thick) of greater strength and ductility than other processes. In agreement with Rajakovics, Rosenberg[40] found that extraordinarily ductile welds are made by the atomic hydrogen process in tubes and sheet of several aluminum alloys (Al-Mg-Si; Al-Cu-Mg) at least up to 0.12 inch thick. Fillet, butt and corner welds can be made without diffi-

culty. Elistratov[41] found that the consumption of tungsten was less in the atomic hydrogen welding of aluminum than of steel, and that less power is required as the current is increased on thin sheet (0.08 inch thick), perhaps because the welding speed is increased. High currents are not economical for thick aluminum (0.32 inch thick). For some reason hot hammering had bad effects, although Rajakovics found hot hammering beneficial, in general. Rajakovics also found that preheating is usually necessary for the atomic hydrogen of aluminum over 0.16 inch thick.

Arc Welding

For arc welding aluminum the "all-purpose" 5% Si rod with flux coating is best, according to Jennings,[50] on account of its low melting point, small solidification shrinkage, and wide melting range. Instructions are: short arc, reversed polarity, currents higher and welding speed three times higher than for plain carbon steel. Excessive amperage is shown by excessive spatter. Preheating is advisable for thick plates. Groebler[51] also states that preheating to 200° C. is necessary only for thick work. He points out that the inherent properties of aluminum make arc welding difficult. The coefficient of thermal expansion is twice that of iron, the specific heat three times and the heat of fusion twice that of iron or copper, and the thermal conductivity is three times that of iron. Besides, unlike FeO, Al_2O_3 has a very high melting point, which, however, is lower than the temperature of the aluminum welding arc.

Experiments on the arc welding of aluminum and its alloys have been made by Auchter.[52] The surface tension of the flux coating is said to be the most important property in avoiding flux inclusions, yet Auchter gives no details of the fluxes he used. He does mention, however, that his electrodes produced weld metal of the same composition as the plate in a wide variety of alloys. The mechanical properties and structure were good. Buchholz[20] had good results with commercial aluminum electrodes in commercial aluminum plate, 1 inch thick.

Horn[53] states that the thick coating on aluminum electrodes usually contains lithium chloride so that the electrode must be stored in wax paper or cellophane, or covered with non-combustible varnish. The grain structure can be refined by using a rod with 0.2% Ti or up to 5% Si. A single layer only should be deposited in plates up to 0.32 inch thick, the amperage being 35 to 40 amp. per mm. diameter electrode for butt welds and slightly higher for fillet welds. Contrary to usual practice, a rapid, rotary movement of the electrode, Roberts[61] states, gives a smooth, regular deposit. Passing aluminum welds between heavy rollers is said to be good practice.

The best coverings for aluminum electrodes containing 5 to 14% Si were found by Begun[54] to be: 1.50% Borax, 25% KCl, 25% NaCl; 2.50% cryolite, 25% NaCl, 25% NH_4Cl. The KCl, NaCl and borax must be dried at 100° C. The powered materials are bonded with waterglass. The coating is 0.024 to 0.039 inch thick on electrodes 0.24 to 0.39 inch diameter, 16 to 20 inches long. For A.C. arc welding Staggs[55] uses a 100 amp. A.C. welder with high frequency superimposed on the secondary. With $^1/_8$–$^3/_{32}$-inch electrodes use 40 amp. on plate 0.051 inch thick, 100 amp. on $^1/_8$-inch plate. Leroy[56] describes the arc-welded aluminum alloy panels (7% Mg, tensile strength 51,000 lb./in.^{2}, elastic limit 25,500 lb./in.^{2}) used on French three-car articulated suburban trains.

Carbon Arc Welding

According to Jennings,[50] carbon arc welding is not so flexible as metal arc for aluminum and its use in confined to simple joints. Hignett[1] recommends the carbon arc for repair work on aluminum castings.

The burn-on method of welding using molten aluminum for joining aluminum electric cables (of Al to Cu) in a stainless steel mold is described by Bunger.[57] Apparently, burning on is better than reaction solder, whose difficulties are set forth by Genz.[58] These difficulties are the only stumbling block in the way of the replacement of copper by aluminum electric cables in German tramways. The insulation must be removed $1^1/_2$ inches back of the joint and the wires cleaned in CCl_4 before the reaction solder may be applied. A patented British aluminum solder[59] is said to develop a tensile strength of 58,000 lb./in.^{2} and to require no flux. A German writer[60] recommends the use of reaction solder for joining tinned brass or steel eyelets to thin aluminum wire. The joint is finished with aluminum soft solder and coated with an acid-free varnish.

REFERENCES (ALUMINUM WELDING)

GAS WELDING

1. Hignett, H. W. G., *Metallurgia*, **15**, 146, March 1937; *Metal Ind.* (London), **50**, 129–136, Jan. 22, 1937.
2. Goodwin, G. S., *Railway Age*, **102** (25C) 1040 D 124, June 23, 1937. *Spot and Seam Welding.*
3. Hoglund, G. O., *American Machinist*, **81** (1) 17–21, Jan. 13, 1937; *SAE Jnl.* (Trans.), **40** (2) 57–64, Feb. 1937.
4. Hartman, F. V., *Mech. Engg.*, **59** (12) 925–929, Dec. 1937.
5. Bohn, D. I., *Metal Progress*, **32** (1) 53–56, July 1937.
6. Osswald, E., *Luftfahrtforschung*, **14** (4/5) 215–223, April 1937. Translation will be sent on request; Ferney, L. A. (*Metal Ind.* London, **51**, (26) 617–622, Dec. 24, 1937) summarizes the elements of spot welding Al alloy.
7. Schober, K., *T Z prakt. Metallb.*, **47** (7/8) 322–326, April 1937.
8. Blank, H. E., Jr., *Automotive Ind.*, **77** (3) 82–88, July 17, 1937.
9. Burns, B., *SAE Jnl.*, **40** (3) 99–107, March 1937.
10. Rosenberg, F., *Aluminium*, **19** (2) 89–97, Feb. 1937; summarized by Rietsch, E., *Maschinenbau*, **16** (17/18) 453–456, Sept. 1937.
11. Eyles, A. J. T., *Sheet Metal Inds.*, **11** (120) 397, June 1937.
12. Orlov, A. S., *Aviopromishlennost* (1) 34–39 (1937).
13. Suhr., O., *Bauing.*, **18** (19/20) 245, May 8, 1937.
14. Lips, E. M. H., *Zeit. Metallkunde*, **29** (10) 339–340, Oct. 1937.
15. Wilson, L. B., *Welding Ind.*, **5** (8) 297–301, Sept. 1937.

GAS WELDING

20. Buchholz, H., *Z. VDI*, **81**, 433–437, April 10, 1937; Maier, M., *Autog. Metallb.*, **30**, 97–102, April 1, 1937; summarized in American Welding Society Journal, Research Supplement, **16** (7) 39–40, July 1937.
21. Rajakovics, E. von, *Z. Metallkunde*, **29** (9) 315–318, Sept. 1937. Translation will be sent on request.
22. Zimmermann, F., *Autog. Metallb.*, **30** (1) 2–10, Jan. 1, 1937.
23. Bollenrath, F., and Gröber, H., *Aluminium*, **19** (6) 355, June 1937.
24. Grahl, F., *Werkstatt u. Betrieb*, **70** (7/8) 93–95, April 1937.
25. Sixt, B., *Autogenschweisser*, **10** (9) 100–101, Sept. 1937.
26. Chevillotte, R., *Sheet Metal Inds.*, **11** (122) 572, June 1937.
27. Herenguel, J., Academie Mediterraneenne, Conference on Sea Water Corrosion, March 1937.
28. Harada, T., *Suiyokwai-Shi*, **9** (3) 175–178 (1937).
29. Anon, *Industry & Welding*, **10** (3) 32–33, 43, March 1937.
30. Anon, *Z. Schweisstechnik*, **27** (3) 48–53, March 1937.
31. Schmitt, H., and Reidemeister, F., *Maschinenbau*, **16** (11/12) 317–318, June 1937. See also Anon, *Rev. Soud. Autog.*, **29** (284) 250–251, Dec. 1937.
32. Jones, O. C., American Welding Society Journal, **16** (6) 32–33, June 1937.
33. Anon, *Aluminium & Non-Ferrous Rev.*, **2** (9) 327–333, July 1937.
34. Buckley, J. P. J., *Modern Engr.*, **11** (7) 390–392, July 1937.
35. Reininger, H., *Leichtmetall*, 6–16, Feb. 15, 1937.
36. Reininger, —, *Metal Ind.* (London), **50**, 436, April 9, 1937.
37. Hignett, H. W. G., *Metal Ind.* (London), **50**, 300, March 15, 1937.
38. Holder, E., *Welding Industry*, **5** (7) 231–233, Aug. 1937.
39. Nischk, K., *Metal Ind.* (London), **50**, 192, Feb. 5, 1937.
40. Rosenberg, F., *Aluminium*, **19** (4) 255–260, April 1937.
41. Elistratov, P. S., *Avtog. Delo*, **8** (8) 7–9, Aug. 1937.
42. Stieler, C., *Elektroschweisser* (6) 63–65, Nov. 1937.

ARC WELDING

50. Jennings, C. H., *Iron Age*, **139**, 60–63, Feb. 4, 1937; see also reference 29, which gives the same instructions.
51. Groebler, H., *Elektroschwg.*, **8** (3) 49–53, March 1937.
52. Auchter, C., *Zeit. Metallkunde*, **29** (9) 310–315, Sept. 1937; summarized by Brenner, P., *T Z prakt. Metallb.*, **47** (19/20) 757–762, (21/22) 831–832 (1937). Translation will be sent upon request.
53. Horn, H. A., *Maschinenbau*, **16** (13/14) 355–358, July 1937.
54. Begun, S. V., *Avtog. Delo*, **8** (4) 39–40, April 1937.
55. Staggs, R. W., *Factory Management & Maintenance*, **95** (4) part 1, 64–65, 96, April 1937.
56. Leroy, M., *L'Allégement dans les Transports*, **5** (3/4) 30–36, April 1937.
57. Bunger, W., and Hammerschmidt, W., *Aluminium*, **19** (2) 86–88, Feb. 1937.
58. Genz, F., *Verkehrstech.*, **18** (17) 410–411, Sept. 5, 1937.
59. Anon, *Automobile Engr.*, **27** (355) 42, Feb. 1937.
60. Anon, *Aluminium*, **19** (5) 322, May 1937.
61. Roberts, P. L., *Ind. Chemist*, **13**, (154) 459–463, Nov. 1937.

APPENDIX IV

Welding Copper and Its Alloys

Aside from the fact that copper alloys consist mainly of copper there is little justification for treating the welding of copper and copper alloys as one subject. The common alloying elements, such as zinc, silicon, aluminum, tin and beryllium, are present in the common alloys to the extent that the alloys of one group possess very few of the characteristics of the alloys of any other group or of copper itself. The alloying elements in their usual percentages completely change the film forming and gas absorbing characteristics of the liquid metal as well as the mechanical properties, melting range, and the thermal and electrical conductivities. Hook's thorough review of literature[1] on the welding of copper and its alloys may be regarded as a source-book on theory and practice, a different theory and practice being applicable to each group of alloys. The following references to 1937 literature, therefore, are classified according to principal alloy content. The spot and seam welding of copper is dealt with in the section on Resistance Welding.

Copper

Hignett's broad and unbiassed discussions of non-ferrous welding always repay the reading, even by the "ferrous" welder. His recent outline[2] of the factors involved in copper welding deals particularly with fluxes and hammering. The purposes of the flux are the reduction of surface tension and the prevention of the molten metal from dissolving surface oxide films. Hammering, if done, must be continued below the recrystallization temperature to avoid grain growth. Hammering of the completed weld is sufficient for deoxidized copper, but each layer should be hammered if the copper contains oxide, if the parts are heavy and under constraint, or if arsenic, bismuth, antimony or lead exceed critical values. Flush machined welds in deoxidized copper should have a tensile strength of at least 24,500 lb./in.^{2} whether or not flux was used or hammering was done. Although the carbon arc generally tends to oxidize the molten metal, good welds may be made with a phosphor-bronze filler rod.

The welding characteristics of copper by the long carbon arc and oxyacetylene processes are reduced as far as possible to quantitative terms by Young,[3] whose original paper should be consulted for information on welding speeds, mechanical properties and microstructure. Excepting Young's work, very little in the nature of research on copper welding has appeared during the past year.

An excellent rod for oxyacetylene welding copper, according to Poncelet,[4] contains 0.05% Si with or without 2.5% Sn and 0.08% P. Silicon is said to act as a deoxidier and to keep gas in solution during solidification. The latter "effect" has been called upon so often to explain the virtues of a pet welding rod that there can be very few who have not smiled on seeing it advanced as an argument once again. *Industrial Gases*[5] recommend a similar rod, with perhaps some silver, but they believe the alloy additions prevent the formation of Cu_2O. Flux must be used on the rod and the edges of the sheet, but the function of the flux is not stated. In contradiction to Hignett, *Industrial Gases* state that hammering, although good, should never be continued below 900° C. A comparison of many papers on copper welding leaves one with the impression that sweat and luck are large factors. The Barimar[6] gas flux method for welding copper depends upon a flux that vaporizes during welding and leaves no inclusions in the weld. The oxyacetylene repair of copper fireboxes is discussed by Hesse[7] and *Energie*.[8] According to Hesse, X welds are used with a rod containing about 1% Ag for high grade welds. Each short section is hammered. The main feature of the oxyacetylene welding of copper, according to Hollard,[11] is that the rod should be kept continually in the weld. Data on the two-torch vertical welding of copper are given by Meslier.[34]

Jennings[9] gives a detailed description of the arc welding of copper. The long carbon-arc process (35–45 volts) with phosphor-bronze rod and without flux depends on high welding speed (10 inches per minute or more) to prevent Cu_2O formation. Welds in deoxidized copper have a tensile strength of 30,000 to 32,000 lb./in.^{2} Shielded arc welds with phosphor-bronze electrodes (short arc, reversed polarity) are also good if the plates are $^1/_4$ inch thick or less. To weld copper to steel shielded copper electrodes are best if the copper plate is $^1/_4$ inch or less; otherwise the long carbon-arc process is best. A translation of an earlier German article on the "sleeve" electrode for metal-arc welding copper has been published in an English welding magazine.[10]

The brazing of copper electrical connections is described by Goeller[12] and Hart.[13] Goeller's tests showed that the best procedure, using a silver solder containing 80% Cu, 15% Ag, 5% P (melts at 1300° F.) was to employ an overlap of three times bus thickness, to sand blast the surfaces to be joined and to place a strip of silver solder 0.01 inch thick and $^1/_{32}$ inch shorter than the lap between the surfaces before clamping. The torch is applied until the alloy runs out at the edges, whereupon the clamps are screwed down tighter and the joint is allowed to cool. The tensile load at fracture of a lap $^1/_2$ x 6 x 1$^1/_2$ inches was 68,500 lb., and the electric resistivity was less than that of a bar of copper of the same size as the bus to be joined. A cost analysis is given. Hart recommends 0.003 inch as a good thickness for the bronze layer between brazed copper bus. The brazing of copper cables depends on the capillary flow of molten brazing metal between the cable strands. Bronze welding is recommended for copper pipe by *Industry and Welding*,[14] who illustrate a number of joints and believe that water quenching improves the properties of the welds, on what basis is left to the reader's imagination. Linick[15] states that the best solder for copper wire consists of 61 parts by weight Sn, 37 Pb, 1 Ag, 1 Cd. Resin is the flux.

Copper rail bonding is best done with a copper electrode (arc length $^1/_4$ inch, 180–200 amp. for $^5/_{32}$-inch electrode, reversed polarity), according to Kingsbury and Smith,[16] who state that carbon arc welding requires a mold. Bainbridge and Dore[17] use a nickel silver rod and an oxyacetylene torch (35 to 40 cu. ft. acetylene per hr.) to weld the bond to the rail head. The rod may contain P or Ag but not Sn. The maximum hardness created in 1% Cr rail steel is 308 Brinell, and in medium manganese rail only 230 Brinell (the rail is softened). Swinnerton[18] agrees with Bainbridge (deoxidized copper bond, backhand welding) and adds that welded rail bonds successfully withstand 13 million cycles of deflections occurring in service.

Copper—Silicon Alloys

According to Hook,[19] the procedure for welding copper-silicon alloys is the same as for cupro-nickel, an adherent flux film protecting the molten metal. MnO, ZnO and SnO_2 are of additional benefit for good fluxing. Jennings[23] states that the black oxide CuO that may be

present on Everdur before welding should be removed with 5–10% H_2SO_4 at 145° F. The short carbon arc process with flux (90% fused borax, 10% sodium fluoride) is best. Peening, if done, must be followed by heat treatment to avoid brittleness. For metal arc welding a bare Everdur electrode is used. The long carbon arc is used for Herculoy (3–3 1/4 Si, 0.5 Sn). Bennett[20] describes the use of metal-arc deposited Herculoy for building up locomotive driving boxes. The welding procedure and qualification tests involved in the use of Everdur in Par. 69 of the A. S. M. E. Unfired Pressure Vessel Code is discussed fully by Reid.[21] Hirner[22] recommends carbon arc welding (5/32-inch carbon electrode, negative, 65 amp.) with 1/8-inch silicon bronze filler rod for silicon bronze. The flux consists of borax and sodium silicate.

Copper—Zinc Alloys

The lower the zinc content of brasses the better is the weldability, according to Jennings.[23] A bare rod is used for carbon arc welding, coated electrode for metal arc, and both are generally phosphor bronze. The arc should not be directed on base metal. Volatilization of zinc causes poor fusion. In the absence of an explanation we may conjecture that loss of zinc raises the melting point and gives rise to ZnO dust which is not wetted by molten brass and may be deposited on the scarves in advance of the filler metal. Kohrs and Radon[24] use metal arc welding for repairing or building up red brass castings (10% Zn, 5% Sn). The electrode is positive and 0.20 inch diam. for the first layer, 0.28 inch diam. for succeeding layers (250–300 amp.). Welding should be done as fast as possible to avoid zinc oxide and blowholes.

Brass is oxyacetylene welded with an oxidizing flame, according to Hollard,[25] the mixture containing 2 parts acetylene to 5 parts oxygen. The zinc oxide formed is practically infusible and so continuous that zinc cannot vaporize through it. Too thick an oxide film is troublesome, of course, but a neutral flame gives rise to zinc flame, spitting and porosity. Filler rod should have the same composition as base metal. A vague statement is made about a flux containing borax and boric acid. A Canadian Journal[26] describes an elaborate system of jigs used to weld bronze side members to a brass pipe 15 ft. long, 6 5/8 inches outside diameter, 1/2-inch wall with Lo-Melt rod (melts at 1225° F.). In Greger's[27] opinion the basic principle in bronze-welding is the formation of a thin alloy layer between deposit and base metal, without melting the latter. There are many indications that other principles are equally vital. Bronze strip for flexible tubing[33] must contain no zinc and is pressure welded by means of a gas flame.

Copper—Aluminum Alloys

There has been considerable activity recently in the welding of aluminum bronzes, particularly the 10% Al alloy. Procedure for oxyacetylene welding is outlined by Boutte[28] and McFalls,[29] who are in complete agreement. The flux is sodium aluminum fluoride (dissolves up to 21% by weight Al_2O_3) to which excess sodium fluoride is added to lower the melting point to 1740° F. This flux appears to absorb metallic aluminum. Consequently the filler rod should contain about 1% excess Al. Fluxes containing sulfate, carbonates or borates of sodium are bad because they oxidize aluminum. With a reducing flame (acetylene feather 3 times the length of the cone) no inclusions have been observed in welds from 0.02 to 1 inch thick. Monel rods may be used if color match is unimportant.

Extensive research on the arc welding of aluminum bronze has been done by Szepanik.[30] The chief difficulty is Al_2O_3 which is not removed by ordinary copper or aluminum fluxes, but which can be fluxed by boron and silicon fluorides. Oxyacetylene and covered metal arc welds in 10% Al bronze 0.24 to 0.39 inch thick had 75% of the tensile strength of base metal and only 40% of the ductility. Becker and Groebler[31] announce that they have developed an electrode (89% Cu, 1% Fe, 10% Al) coated with inorganic, non-hygroscopic salts, which, with a technique similar to that for aluminum itself, can be depended upon to produce excellent welds. Since they prefer not to tell the composition of the flux, their paper becomes an advertisement having slight technical interest.

Other Copper Alloys

According to Hignett,[2] tin bronzes are welded like copper. Jennings[23] states that tin bronzes are very fluid when molten and should always be arc-welded downhand. Vertical welds may be made with coated electrodes. Unless color match is important, phosphor bronze filler rods (carbon or metal arc) are used. Beryllium-copper alloys can be silver soldered, according to *Industrial Heating*,[32] but all parts must be kept between 780 and 865° C. Quench after soldering and reheat to about 300° C. to complete the hardening.

REFERENCES (COPPER AND COPPER ALLOYS)

1. Hook, I. T., American Welding Society Journal, **16**, Research Suppl., (2) 7–32; (3) 33–46 (1937); *Metal Ind.* (N.Y.) **35** (9) 434–437; (10) 498–501; (11) 555–556 (1937).
2. Hignett, H. W. G., *Metallurgia*, **15**, 146, March 1937.
3. Young, A. P., American Welding Society Journal, **16** (10) Research Suppl., 30–40, October 1937.
4. Poncelet, E., *Bull. Tech. Union Ing. Louvain*, **43** (2) 1937.
5. Anon., *Industrial Gases*, **18** (2) 70–71 (1937).
6. Anon., *Sheet Metal Inds.*, **11** (126) 931, Oct. 1937.
7. Hesse, R., *Autogenschw.*, **10** (5/6) 54–55, June 1937.
8. Anon., *Energie*, **16** (1) 10–13 (1937).
9. Jennings, C. H., *Iron Age*, **139**, 60–63, Feb. 5, 1937.
10. Matting, A., and Lessel, W., *Welding Industry*, **5** (2) 63–66; (3) 93–97 (1937).
11. Hollard, P., *Cuivre et Laiton*, **10**, 65–67, Feb. 15, 1937.
12. Goeller, R. A., *Electrical World*, **108** (19) 64–66, 122, 124, Nov. 6, 1937 *Weld. Engr.*, **22** (12) 34–35, Dec. 1937.
13. Hart, W. J., *American Machinist*, **81** (17) 734–736, Aug. 25, 1937.
14. Anon., *Ind. & Weld.*, **10** (6) 38–41, June 1937.
15. Linick, L. L., *Intnl. Projectionist*, **10** (3) 14, March 1936.
16. Kingsbury, C. R., and Smith, F. F., *Coal Age*, **42** (8) 361–363, Aug. 1937.
17. Bainbridge, C. G., and Dore, R. E., *Zeit. Schweisstech.*, **27** (1) 4–7 Jan. 1937.
18. Swinnerton, N. W., *Welding Ind.*, **5** (5) 180–188, June 1937.
19. Hook, I. T., *Ind. & Weld.*, **10** (1) 61–63, Jan. 1937.
20. Bennett, I. T., American Welding Society Journal, **16** (10) 37–43, Oct. 1937.
21. Reid, C. W., *ibid.*, **16** (3) 5–7, March 1937.
22. Hirner, F., *ibid.*, **16** (7) 27, July 1937.
23. Jennings, C. H., *Iron Age*, **139**, 44–47, Feb. 11, 1937.
24. Kohrs, —, and Radon, —, *Elektroschwg.*, **8** (7) 128–131, July 1937; *Welding Ind.*, **5** (7) 235–237, Aug. 1937.
25. Hollard, P., *Sheet Metal Inds.*, **11** (123) 660–661, July 1937.
26. Anon., *Canadian Machinery*, **48** (5) 47–50, May 1937.
27. Greger, —, *Autogenschw.*, **10**, Sonderheft, 14–15, May 1937.
28. Boutte, A., *Automotive Inds.*, **76**, 593, April 17, 1937.
29. McFalls, C. D., *Ind. & Weld.*, **10** (8) 46, Aug. 1937.
30. Szepanik, H., *Elektroschwg.*, **8** (2) 28–32; (4) 69–76; (5) 93–94 (1937).
31. Becker, G., and Groebler, H., *ibid.*, **8** (7) 132–134, July 1937.
32. Anon., *Industrial Heating*, **4** (4) 281–282 (1937).
33. Anon., *Iron Age*, **139** (19) 60–61, May 13, 1937.
34. Meslier, R., *Rev. Soud. Autog.*, **29** (285) 276–278, Dec. 1937.

APPENDIX V

Flame Cutting

Flame cutting of steel depends on the self-sustaining reaction of iron with oxygen above the ignition temperature, 1500° F., states Slottman[1] in his exposition of the fundamentals of flame cutting. The cut is 30 to 40% molten metal, the remainder Fe_3O_4. The drag should

be as low as possible for dimension cutting; about 70 cu. ft./hr. cutting oxygen produces minimum drag in 1-inch mild steel plate.

The cutting jet itself has been examined by Bullock[2] with the aid of high-speed motion pictures. Turbulence in the jet is caused by a periodic mechanical shock in the nozzle, the origin of which is unknown, but which disturbs the velocity of the reaction between oxygen and iron, and creates a rough cut surface. Zobel's nozzle for producing a parallel cutting jet without sudden loss of energy by sudden expansion from nozzle pressure to atmospheric is referred to by Diergarten.[3] The nozzle cuts 1-inch mild steel plate at the rate of 20 inches/min., 8-inch plate at $7^3/_4$ inches/min., using 90 and 340 lb./in.^{2} oxygen pressure, respectively. Sloping cuts can be made without a wavy surface.

For those who object to the term "cutability" on grounds of euphony, Daniel and Durant[4] facetiously propose "sectile divisibility." For oxyacetylene cutting of mild steel

$$\log S = 1.69 - 0.41 \log T$$

where S = cutting speed, ft./hr.

T = plate thickness, inch

Also $Q_h = 1.4\ T + 17.8 = 0.022\ Q_c + 16.5$

where Q_h = cu. ft. heating oxygen per hour

Q_c = cu.ft. cutting oxygen per hour.

Experience shows that the correct distance of the tip from the work in sixteenths of an inch is $0.43\ T + 2.3$.

Daniel and Durant clearly show the superiority of the oxyacetylene flame for preheating over any other common combination. The neutral oxyacetylene flame (1:1 ratio) liberates 200,000 b. t. u. per molecular volume C_2H_2, whereas the oxypropane liberates only 100,000 b. t. u. For complete combustion, which does not take place under practical conditions, 1 vol. C_2H_2 requires $2^1/_2$ vol. O_2, whereas the ratio is 1:5 for propane. Keel[5] also states that 120% more oxygen is required for flame cutting with propane, butane or illuminating gas than with acetylene. Nevertheless, there are those who believe other combustibles are superior to acetylene for the preheating flame of the cutting torch. In particular, Dijkerman[6] found a lower gas consumption for oxypropane than for oxyacetylene. The preheating tip for oxypropane has six holes each 0.047 inch diam.; pressures are $6^1/_2$ lb./in.^{2} for propane, 54 lb./in.^{2} oxygen, in which case the cutting time is the same as for oxyacetylene. The oxypropane flame temperature, though only 2500° C., is adequate for flame cutting steel, manually or mechanically. Dobson[7] found that 60° V welds in 0.40-inch ship plate were satisfactory when the scarves were machined or cut with an oxy-coal gas torch but were not satisfactory when oxyacetylene was used for preheating flame (no explanation). For riser cutting Andrews and Jamison[8] prefer propane for a number of reasons including the alleged fact that propane produces a cleaner cut on dirty castings presumably because the oxypropane flame is more oxidizing than the oxyacetylene. Their results will not convince many. An Australian writer[9] points out that, if necessary, oxy-coal gas may be used for flame cutting, but a compressor is required to build up to coal gas to 12 lb./in.^{2} at the torch. An inductor type torch may be used provided the oxygen for cutting is kept independent of the preheat oxygen. Illuminating gas is favored by Van Pareren[33] who shows that although large volumes are required, gas is cheaper than other fuels. Cochrane[34] states that illuminating gas may be substituted for acetylene in machine cutting.

Besides bringing sound reason to bear on the combustible question, Daniel and Durant[4] provide some facts on the "carbon-migration" hypothesis. Asked whether carbon tended to migrate from the interior of the steel toward the cut edge, Helmkamp and Bass[10] both replied in the affirmative. Helmkamp qualifies his statement to the extent that migration of carbon to the cut edge is observed only when the carbon content of the steel exceeds 0.30%. However, Daniel and Durant state that there may be some pickup of carbon at the edge (not migration to the edge from the interior), sometimes none, but they have never observed decarburization.

Systematic studies of the mechanical properties of machine flame cut boiler plate 0.79 to 1.58 inches thick (0.10 C, 0.40 Mn; 0.18 C, 0.47 Mn) have been reported by Hessler and Dümpelmann.[11] Hydrogen as well as acetylene were used as preheating gases. Tensile, roller bend, notch impact, and drift pin tests showed that the flame cut surface had up to 20% better properties, including ductility, than milled surfaces. The notch-impact value of the oxyhydrogen cuts was 50 to 100% higher than milled, the notch-impact value of the oxyacetylene cuts was 30 to 50% higher than milled (cross section of fracture was 0.79×0.59 inch). The hardness of the flame cut surface, determined by means of a 2.5 mm. ball, 187.5 kg. load, was maximum at mid thickness (180 Brinell max. for 0.18 C steel). The authors conclude that flame cutting is an acceptable process for steels containing up to 0.3 C, at least. Similar results were obtained by Dümpelmann[12] with steels containing 0.13 C, 1.00 Mn, 0.60 Si, 0.42 Cu, 0.1 Mo; and 0.12 C, 1.00 Mn, 0.62 Si, 0.26 Cu, using illuminating gas as well.

Pulsating bending fatigue tests by Graf[13] on flame cut medium carbon steel (composition not stated but 99,000 lb./in.^{2} tensile strength, 50,000 lb./in.^{2} yield strength, 32% reduction of area) indicated a fatigue limit of 42,500 lb./in.^{2} (1×10^6 cycles), which was the same as that obtained on flame-cut low-alloy structural steel (74,000 lb./in.^{2} tensile strength). However, the fatigue limit of a flame-cut surface after the irregularities had been milled off was 79,000 lbs./in.^{2}, compared with only 68,000 lb./in.^{2} for the low-alloy steel after similar treatment. From the standpoint of welded ship construction, according to Tetzlaff,[14] metal arc welds (butt and fillet) show no difference in tensile strength whether the scarves are sheared or flame cut. Butt welds (2 layers) on flame cut scarves (0.32-inch mild steel) had better bend ductility than on sheared scarves, because the flame cut edge is sharper and the grain is refined.

The procedure for flame cutting stainless steels is outlined by Judelsohn.[15] The torch is advanced in a series of backward and forward motions, using a neutral preheating flame. Apparently, the method is useful only for scrap cutting, not for close dimension cutting. Practically the same procedure is described by Tupholme;[16] a riser 6 inches square is cut in 3 to $3^1/_2$ minutes. A French writer[17] recommends the use of a steel rod 0.16 inch diameter in flame cutting 18–8, but the cut surface has a very irregular appearance. The preheat flame must be neutral or slightly reducing. It is stated without details that chromium steels containing 14 to 24% Cr can also be flame cut. Table 1 applies to the manual flame cutting of cast iron with the aid of a steel rod. The flame cutting of stainless clad and nickel-clad steel, according to Inskeep,[18] is done from the mild steel side, the molten mild steel and slag cutting the stainless by melting and eroding it. Higher oxygen pressures, larger nozzles and slower speeds are required than for mild steel. The cladding does not peel.

An example of avoidance of distortion in flame cutting is given by Cooper.[19] To avoid distortion in cutting a strip 12 inches wide, 20 ft. long from a 3-inch plate,

Table 1—Manual Flame Cutting of Cast Iron with a Steel Rod[17]

Thickness, Inch	Nozzle Diameter, Inch	Diameter of Steel Rod, Inch	Oxygen Pressure, Lb./In.²	Speed, Ft./Hr.	Consumption of Steel Rod, Feet per Foot of Cut	Oxygen Consumption Cu. Ft./Sq. In.
2	0.008	0.16	57	10	10	1.2
8	0.010	0.24	100	5¼	14	1.6
14	0.018	0.32	140	4	17	1.8

the cuts were made simultaneously starting 3 inches from one end and finishing 3 inches from the other end. After the plate had cooled the remaining 3-inch cuts were made. Kerf allowance, according to *Canadian Machinery*,[20] is 1/32 inch for a plate 1/4 inch thick, but 1/8 inch for a plate 4 inches thick. A jig for flame cutting bolt holes in the webs of rails is described by Grygotowicz.[21] Some danger is usually believed to attend the flame cutting of holes in rails. Shop hints are given by Ross[22] on flame cutting, dressing of tips, repairing leaky seats and making patterns for cutting machines. *Nickel Steel Topics*[23] states that S.A.E. nickel steels with over 0.30–0.35% C should be preheated to 500–600° F. before being flame cut. If the carbon content exceeds 0.50% annealing at 1450–1500° F., as well as preheating, is necessary, depending on size, shape and other factors. The economics of flame cutting in shipbuilding is discussed by Holbrook,[31] whose paper is summarized by Faerman.[32] French practice, as Faerman points out, differs from American in many respects, notably in the avoidance of joggled joints. According to Cochrane,[34] recognized maximum shop run tolerance for good flame cutting is 1/16 inch per cut.

Riviere's[24] chart showing the relation between gas consumption, thickness and angle of bevel in machine cutting scarves for welding shows that up to 15° the angle of bevel has no effect, but for 45° bevel the gas consumption must be increased 2 to 3 times. Churin[25] outlines the steps in the manufacture of a Russian flame cutting machine rated at 16 to 19 inches/min. for mild steel 0.20 inch thick, and 5 to 6 inches/min. for steel 4 inches thick. The range of the machine described by Orr[26] for flame cutting stacks of plate is 24 ft. longitudinally, 81 inches transversely. When 1/4-inch plate is to be cut, 12 plates are stacked, this number having been arrived at by a study of time and cost factors. The edges never fuse together.

Underwater cutting with a submarine torch in which the flame burns in a cone of compressed air was used to a considerable extent at Bonneville Dam.[27] A redesigned Ellsberg[28] underwater cutting torch (no details) was used for severing the sheet steel (3/8 inch thick) cofferdams around 2100 concrete bridge piers, 30 feet below the surface of the water. Ellsberg and Kandel detail the costs and supply a table showing the factors affecting the speed of underwater cutting. The Picard H_7 underwater cutting torch[29] operates on hydrogen instead of acetylene. It is said that acetylene can be used to a depth of 35 ft., whereas hydrogen may be used at a depth of 130 ft.

A summary of what is known about arc cutting is given by Jennings.[30] Graphite electrodes and high currents (300 to 600 amp. for 1/2-inch electrode). Since arc cutting depends solely on melting, not on oxidation, steel and cast iron are cut at the same rate (3.2 inches per minute for plates 1 inch thick). If cutting is to be done with steel welding electrodes, a slag coating, which handles higher currents, is preferable to a gaseous type coating. At 600 amp. a 2-inch plate can be cut at 2 inches/min., steel or cast iron. The width of the cut is constant for electrodes from 5/32 to 1/4 inch diameter.

REFERENCES (FLAME CUTTING)

1. Slottman, G. V., American Welding Society Journal, **16** (2) 9–13, Feb. 1937.
2. Bullock, H. R., American Welding Society Journal, **16** (10) Research Suppl., 50–52, Oct. 1937.
3. Diergarten, H., *Metal Progress*, **32** (1) 68, 74, July 1937.
4. Daniel, N., and Durant, C. E., *Welding Ind.*, **5** (1) 24–34, Feb. 1937.
5. Keel, C. F., *Z. Schweisstechnik*, **27** (2) 22–24; (6) 124–125 (1937).
6. Dijkerman, A. G., *Laschtechniek*, **3** (11) 134–136, Nov. 1937.
7. Dobson, N., *Sheet Metal Inds.*, **11** (122) 565–570, June 1937.
8. Andrews, F. H., and Jamison, E. A., *Trans. American Foundrymen's Assn.*, **7** (6) 324–333, Dec. 1936.
9. Anon., *Modern Engr.*, **11** (6) 334–335, June 1937.
10. Helmkamp, R. F., *Southern & Southwestern Rwy. Club Proc.*, **24** (14), May 1937; Bass, H., American Welding Society Journal, **16** (10) 18–21, Oct. 1937.
11. Hessler, R., *Wärme*, **60** (9) 137–148, Feb. 27, 1937; Dümpelmann, R., *Autog. Metallb.*, **30** (4) 49–52, Feb. 15, 1937.
12. Dümpelmann, R., *Autog. Metallb.*, **30** (13) 219–223; (17) 289–296 (1937).
13. Graf, O., *Autog. Metallb.*, **30** (19) 321–323, Oct. 1, 1937.
14. Tetzlaff, L., *Schiffbau*, **38** (3) 34–40, Feb. 1, 1937.
15. Judelsohn, F., American Welding Society Journal, **16** (3) 14–15 March 1937.
16. Tugholme, C. H. S., *Welding Ind.*, **5** (5) 160–161, June 1937.
17. Anon., *Soudeur-Coupeur*, **12** (8) 1–5, Oct. 1937.
18. Inskeep, H. V., American Welding Society Journal, **16** (8) 2–5, Aug. 1937; *Oxy-Acet. Tips*, **16** (7) 149–153, July 1937; *Mech. World & Engg. Rec.*, **102** (2638) 79–81, July 23, 1937.
19. Cooper, J. H., *Weld. Engr.*, **22** (7) 22–23, July 1937; American Welding Society Journal, **16** (8) 27–28, Aug. 1937.
20. Anon., *Canadian Machinery*, **48** (3) 55–56, March 1937.
21. Grygotowicz, A., *Spawanie i ciecie Met.*, **10** (5) 89–91, May 1937.
22. Ross, P., *Weld. Engr.*, **22** (7) 20–22; (8) 31–33 (1937).
23. Anon., *Nickel Steel Topics*, **6** (4) 10, Aug. 1937.
24. Riviere, M., *Soudeur-Coupeur*, **12** (4) 12–16, April 1937.
25. Churin, V. S., *Sudostrojenye*, **7** (5) 347–355, May 1937.
26. Orr, B. F., *Weld. Engr.*, **22** (1) 39–41, Jan. 1937; *Sheet Metal Inds.*, 11 (119) 307–308, March 1937.
27. Young, H. W., *Weld. Engr.*, **22** (3) 20–21, March 1937.
28. Ellsberg, E., and Kandel, C., *Engg. News Rec.*, **118**, 373–375, Mar. 11, 1937; American Welding Society Journal, **16** (4) 31, April 1937.
29. Anon., *Soudeur-Coupeur*, **12** (1) Jan. 1937; (9) 34–41, Nov. 1937.
30. Jennings, C. H., *American Machinist*, **81** (20) 916–919; Oct. 6, 1937.
31. Holbrook, G., American Welding Society Journal, **16** (2) 16–20, Feb. 1937.
32. Faerman, W., *Bull. Tech. Bureau Veritas*, **19** (7) 145–146, July 1937.
33. Van Pareren, D., *Laschtechniek*, **3** (12) 149–150, Dec. 1937.
34. Cochrane, A. G., *Mech. Engg.*, **59** (10) 733–737, Oct. 1937.

APPENDIX VI

Arc Phenomena

The Welding Arc

There is a nearly complete absence of recent research on the physics of the arc with the outlook of the arc welder (metal transfer, atmosphere and temperature). An elementary discussion of the welding arc that makes easy reading has been prepared by Osborne,[1] who explains the use of oscillograms in the study of the welding arc. Newell[2] has made an interesting drawing to show what goes on inside the arc space. The principal feature is the explosion of molten globules during transfer owing to the expansion of trapped gas. The ratio of volume of metal deposited per hr. to the welding current is called by Schnadt[3] the "coefficient of fusion." The volume deposited by a given type of electrode at a given current is said to be independent of electrode diameter. According to Smith,[4] the only occasion on which shielded arc-weld-metal is of particularly poor quality is when the voltage is too low. Speed of welding has no effect on the sound of the arc.

At the commonly assumed temperature of 3700° C. for the welding arc the N_2 and O_2 are less than 2% dissociated. But *Electric Welding*[5] has observed the arc temperature for heavy coated electrodes to be 5700° C., at which N_2 and O_2 are about 80% dissociated. This increase in dissociation probably increases the heat transfer over 80%. At 6200° C. dissociation of air is

practically complete so that any gain in heating above 6200° C. will be obtained chiefly by using a greater volume of gas. Straight polarity, Ronay[6] has found, prevents the bifurcated arc (striking to sides instead of root), but reversed polarity gives hotter weld metal and better "penetration."

Using a Wulf string electrometer, Sack[7] found that the drops from a coated iron welding rod (no details of size or composition) were always negatively charged (about 0.0025 microcoulombs for a drop weighing 0.2 gm.) whether the electrode were connected to positive or negative terminal or operated on A.C. The charge corresponded to a potential of 10,000 volts on the insulated drop. No explanation has been evolved.

Probe measurements (0.031 inch copper wires connected to an oscillograph) were made by Conrady[8] on arcs in air at atmospheric pressure between iron, copper and aluminum electrodes 1.58 inches diameter. The probes were passed perpendicular to the axis of the arc and also obliquely to touch the electrodes so as to determine the voltage-distance curve in all parts of the arc. The cathode fall was always greater than the anode fall, particularly in iron, as shown in Table 1. The current

Table 1—Cathode and Anode Fall in Air. Conrady[8]

Electrode Material	Cathode Fall	Anode Fall
Iron	16–17 volts	6–9
Copper	13–12	11–10
Aluminum	14–13	11–10

was 50 to 250 amp., electrode distance 0.24 to 0.95 inch, voltage 32 to 45 volts, increasing as current was increased. With increasing current the anode and cathode fall rises with iron but decreases with copper and aluminum. Unlike copper and aluminum, the iron arc burns from a small anode spot, spreading out to a large cathode area. For this reason bare iron welding electrodes are always connected to the negative pole, copper always to the positive. The aim of further research is to study the heat and smoothness of arcs so that the effects of coatings can be predicted from their effect on the arc as well as on metallurgical grounds.

Arcs in General

Dow's[9] chapter on electric arc and glow discharges is a useful summary of the present situation. The viewpoint adopted is that of ion and electron mobilities and drift velocities. The best available empirical formula for the volt-ampere curve of an arc is

$$E_a = A + \frac{B}{I_a^n}$$

where E_a = arc voltage
I_a = arc current

and $n = 2.6^2\ T_b \times 10^{-4}$, T_b being the boiling or sublimation temperature of the anode material. A and B are empirical constants which vary with arc length. Cyclic variations of current and voltage in 60-cycle pulsating arcs at atmospheric pressure follow static arc characteristics fairly closely, but 600-cycle arcs depart considerably. The cooling effect prevents operation of an arc on 110 volts A.C. between metallic electrodes other than tungsten.

Suits[10] has continued his investigation of the effects of pressure (from a vacuum up to 1200 atmospheres) on arcs between W, Cu and C electrodes in N_2, H_2, He and A. The total arc voltage e was measured as a function of current i, electric gradient E and current density I, which was assumed to be constant over the cross section of the arc. As the pressure was increased 100 fold, e increased about 2 times, E 3 times and I 15 times. At 100 atm. $E_{calc}/E_{obs} = 1.32$, where E_{calc} is calculated on the basis of variation of electron density and arc temperature with pressure. The dependence of arc temperature on arc length and current is small. The striking result achieved is that the arc characteristics in different gases are exactly the same if the pressures are so chosen that the gases have the same effectiveness in transferring heat.

Working with 2-amp. arcs between copper, silver and iron electrodes, Schmidt[11] found that the arc voltage was lower as the cathode was heated to the melting point. For example, with an arc length of 0.16 inch, a cooled cathode resulted in an arc voltage of 61 volts, but if the cathode were heated to the melting point the voltage was 42. Schmidt concludes that arc conditions are controlled largely by heat transfer at the cathode. The temperature of the axis of a carbon arc depends to a great extent on the current, according to Lochte-Holtgreven,[12] who found that for an arc 0.12 inch long between carbon electrodes 0.55 inch diameter the temperature was 7600° K at 14 amp., 6700° K at 18 amp., and 8700° K at 22 amp. The temperature was measured by photometric observation of a CN band head (3883Å) obtained through 0.08-inch holes drilled through the axes of the electrodes.

The carbon arc in air at atmospheric pressure has been studied by Mason[13] with the aid of probes (round or rectangular copper wires or a 1-inch length of tungsten filament from a 60-watt Mazda lamp). The carbons were $^1/_2$ inch diameter, the arc was 0.32 to 0.36 inch long, and the current was 6 amp. The energy absorbed by the probe, which was surrounded by a cool dark space several times the probe diameter, was about 50 watts per cm. length, half of which came from the recombination of oxygen and nitrogen on the surface and half from thermal conduction across the dark space. Only when the probe passed the central core where most of the arc energy originates did it cause any decrease in arc energy. The anode fall was 20 volts, the cathode fall more than 10 volts (total arc voltage = 74; gradient = 33 volt/cm.). It is calculated that the ion density in the arc is 10^{14} per cm.^{3} and that the temperature falls from 4000° K 0.20 inch from the core of the arc to 2000° K at 0.36 inch, the core temperature being 6000° K (assumed). The contraction of the positive column that is observed when the pressure rises above a few mm. Hg is believed to be due to the increase in gas temperature.

The reignition potential of the A.C. carbon arc in nitrogen, oxygen and air (graphite electrodes, up to 0.08 inch spacing, and up to a pressure of 500 cm. Hg) after passing through current zero was found by Power and Cobine[14] to be a function of the product of gas pressure and separation of electrodes (Paschen's Law). The higher the current the lower need be the re-applied voltage or the less rapidly (cycles per sec.) it need be applied if deionization is to be arrested.

Continuing his study of the carbon arc, Newman[15] found that ignition of a cold cathode in vacuum occurs not by thermal effect but by a rapid surge of positive ions to form the positive ion space charge at the cathode. Arcs between all metals in vacuum can be started by an electric discharge at right angles to the axis of the separated electrodes across which there is adequate potential difference. Useful tables and charts showing volt-amp. characteristics of D.C. low- and high-intensity carbon

arcs, and on crater areas as on function of diameter of positive carbon have been prepared by Kalb[16] in connection with his study of spectral energy distribution in carbon arc lights.

Another popular arc, the mercury arc, has been the subject of considerable research. Anderson and Bird[17] describe a new type of hot, high-pressure mercury vapor arc (up to 2 or 3 atm.) which is made of quartz with solid, oxide-coated metallic electrodes (nested, spot-welded nickel cups). The minimum gradient for the maintenance of a high-pressure mercury arc (1 atm.), according to Elenbaas,[18] varies directly as the $^{7}/_{12}$ power of the amount of vaporized mercury per cm. length and inversely as the $^{3}/_{2}$ power of the diameter of the column. Above 1 atm. the relation fails to hold. Later measurements[19] on the gradient in high-pressure discharges in quartz glass tubes filled with cadmium or zinc vapor (oxide coated electrodes) showed the same type of relationship as for mercury, the constants being different but close to expectations. Observations on the convection currents in mercury vapor lamps (2.9 amp. arcs in 1.30-inch vertical tubes filled with Hg vapor at 1 atm.) made visible by incandescent particles of MgO, according to Kenty,[20] showed that there is a strong upward current in the core (3 to 7 ft./sec.) and a slower downward current of cold gas at the walls.

The new dark space or layer between the Langmuir space charge layer (than which the new layer is 20 times thicker) and the plasma in low-pressure arcs in mercury and noble gases when the current density is above 0.1 amp./cm.^{2} and the pressure is 0.02 (for Hg) to 3 mm. mercury (for helium) has been studied further by Druyvestyn.[21] At the edge of the new layer there is a sharp increase in concentration and decrease in mean energy of the fast electrons. Druyvestyn[22] also found that the condition for an anode fall in a hot cathode arc in noble gases at pressures from 1 to 50 mm. Hg is a critical value of distance between electrodes, which is the same as that for the appearance of an anode fall in a glow discharge.

If a critical current density in a low-pressure arc is exceeded, the arc suddenly opens circuit. Tonks[23] traces the cause to four factors: (1) the longitudinal and (2) the transverse pressure gradient, (3) the magnetic pinch effect, and (4) the pressure difference (or pumping action of ions and electrons) in constricted openings created by the "double sheath" composed of electron space charge directed toward the cathode and positive ion space charge directed toward the anode. Experiments by Gvosdover[24] indicate that the present theory of probes at low pressures requires modification at high pressures.

Fry[25] distinguishes four forms of the copper arc in atmospheric air depending on whether the electrodes are metallic copper, hot Cu_2O, cold CuO, or hot CuO. The controlling gas in the arc between clean copper electrodes is nitrogen, but with hot oxides the copper vapor from decomposition of the oxides determines the gradient. The least striking voltage for an arc, Fink[26] found, is in the vicinity of the ionization potential of the metal concerned (Zn, Pb, Ag, Cu, Ni, Pt, W, Fe). The anode metal in heterogeneous arcs plays the more important part in determining arc characteristics. The equation evolved (but not communicated) to determine the boundary characteristics of the shortest arc length involved the sublimation or boiling point of the metal.

Of possible application in certain types of welding is the investigation reported by Läpple[27] on arcing in sand-filled fuses. The arc formed after the melting of an overloaded A.C. silver fuse wire embedded in quartz or marble dust (0.008-inch grain size) has a rising characteristic with respect to current but a falling characteristic with respect to time. At zero current part of a wave, quartz, which does not evolve gas, gave rise to smaller current peaks at ignition and less steep decrease after the peak than marble, which liberates CO_2. The arc has a high voltage on account of the cooling action of the powder. Sintering of the powder often occurred.

Kurzke[28] found that the normal cathode fall of bismuth single crystals in argon at a pressure of 1 mm. Hg depends on the orientation of the surface and is 3 to 4 volts greater for $11\bar{1}$ than for 111. The characteristics of the arcs formed on flashing commutators have been studied by Hellmund[29] as a function of speed of rotation.

REFERENCES (ARC PHENOMENA)

1. Osborne, S. C., American Welding Society Journal, **16** (6) 11–15, June 1937.
2. Newell, E. F., *Electric Welding*, **6**, New Series (34) 102–104, April 1937.
3. Schnadt, H. M., *Arcos*, **14** (78) 1621–1622, March 1937.
4. Smith, E. W. P., *Weld. Engr.*, **22** (2) 37–39, Feb. 1937.
5. Anon., *Electric Welding*, **6**, New Series (33) 71, Feb. 1937.
6. Ronay, B., *Weld. Engr.*, **22** (1) 24–25; (3) 30–31 (1937).
7. Sack, J., *Physica*, **4** (2) 104–106, Feb. 1937.
8. Conrady, H. V., *Elektroschwg.*, **8** (6) 101–106; (7) 125–128, June, July 1937.
9. Dow, W. G., *Fundamentals of Engineering Electronics*, John Wiley & Sons, N. Y., 426–454 (1937).
10. Suits, C. G., *Phys. Rev.*, **52**, Second Series, 245, Aug. 1, 1937; Suits and Poritsky, H., *ibid.*, 136, July 15, 1937.
11. Schmidt, R. W., *Zeit. Physik*, **106**, 35–48 (1937).
12. Lochte-Holtgreven, W., and Maecker, L., *Zeit. Physik*, **105**, 1–15 (1937).
13. Mason, R. C., *Phys. Rev.*, **51**, Second Series (1) 28–42, Jan. 1, 1937.
14. Power, R. B., and Cobine, J. D., *Jnl. Applied Physics*, **8** (4) 287–290, April 1937.
15. Newman, F. H., *Phil. Mag.*, Series **7**, **23**, 181–186 (1937).
16. Kalb, W. C., *Elect. Engg.*, **56** (3) 319–324, March 1937.
17. Anderson, W. T., Jr., and Bird, L. F., *Jnl. Optical Soc. America*, **27** (3) 95–99, March 1937.
18. Elenbaas, W., *Physica*, **4** (4) 279–284, April 1937.
19. Elenbaas, W., *Physica*, **4** (8) 669–682, Aug. 1937.
20. Kenty, C., *Phys. Rev.*, **51**, Second Series (11) 1025, June 1, 1937.
21. Druyvestyn, M. J., and Warmoltz, N., *Physica*, **4** (1) 41–50, 51–68, Jan. 1937.
22. Druyvestyn, M. J., *Physica*, **4** (8) 669–682, Aug. 1937.
23. Tonks, L., *Electrochem. Soc. Preprint* 72–13, 185–200, Oct. 18, 1937.
24. Gvosdover, S., *Tech. Phys. U. S. S. R.*, **4** (9) 717–721 (1937).
25. Fry, A. S., *Phys. Rev.*, **51** Second Series (1) 63, Jan. 1, 1937.
26. Fink, H. P., *Naturwissenschaften*, **25** (18) 284, April 30, 1937.
27. Läpple, H., *ETZ*, **58** (14) 369–372; (16) 426–428, April 1937.
28. Kurzke, H., *Zeit. Physik*, **104**, 735–743 (1937).
29. Hellmund, R. E., *Elect. Engg.*, **56** (1) 107–113, Jan. 1937.

APPENDIX VII

Gas Welding

The theoretical aspects of oxyacetylene welding are clearly outlined by Slottman.[1] The particular value of acetylene for welding is that it generates an extremely high temperature (6000° F., 3300° C.) in a reducing atmosphere. Ribaud[2] calculated the theoretical temperature of combustion of acetylene in oxygen as 3100° C., in air 2210° C. The theoretical temperature of the methane and propane flames in oxygen were calculated to be 1880 and 1930° C., respectively. The sodium-line reversal method of measuring the temperature of open flames (Bunsen flames were in question) is not considered by David[3] to be a reliable means of measuring true temperature, which is defined as being proportional to the mean molecular translational energy. Platinum thermometry indicated flame temperatures 200 to 500° C. lower than calculated for CO–O_2 mixtures, 20 to 55% CO, but even these may be overestimates of the true temperature. The possible chemical reactions of hydrogen and oxygen above the explosion limit with respect to composition, temperature and pressure are outlined in an interesting way by von Elbe and Lewis,[4] who discuss chain initiating reactions at surfaces, and point out that streams of hydrogen and oxygen will catch fire without the aid of a surface when crossed at 650° C. at atmospheric pressure. A thorough study of the metallurgy of oxyacetylene weld metal and slags in low- and high-

carbon steels has been made by Stursberg[5] who also studied hardness, microstructure, tensile, bend and notch-impact value as a function of torch adjustment. A convincing proof that the acetone content of acetylene in cylinders depends solely on the vapor pressure of acetone is given by Mies.[6] The acetone content varies from 1% in winter (average temperature 2° C.) to 3% in summer (average temperature 17° C.).

All oxyacetylene welding methods are dealt with briefly in Trunschitz's[7] review. The two torches required for the two-torch vertical welding of steel need deliver only 2.7 cu. ft. acetylene per hr. per inch thickness. The torch for right-hand welding of steel must deliver 8.9 cu. ft. acetylene per hr. per inch for all thicknesses up to 1.18 inches. In two-torch vertical welding the gap is one-half the plate thickness up to $^1/_2$ inch, above which 0.12 to 0.16 inch is correct. Plates up to $^1/_2$ inch thick are not beveled; above $^1/_2$ inch the 80° X weld is used. The method can be used for copper and brass. All non-ferrous metals, except lead, require flux for oxyacetylene welding. A French welding magazine[8] gives complete instructions for two-torch vertical welding, and *Industrial Gases*[9] presents detailed figures on the two-torch vertical welding of gas holders 10 ft. high, 16 ft. diameter, made of $^3/_{16}$-inch low-carbon steel. The two-torch vertical method is easy to apply to horizontal welds. Bainbridge[10] states that the process is applicable to plates over $^3/_{16}$ inch thick, neutral flame. The welders can sit down while two-torch vertical welding the axial seams of steel tanks, 1800 cu. ft. capacity, $^3/_8$ inch thick, as the tanks are slowly lowered past them into a pit, Meslier[11] shows.

A better name for left-hand or forehand welding, according to Thiesen,[12] is "welding with torch between rod and puddle;" for right-hand or back-hand welding, a better term is "welding with torch before rod and puddle. The two processes have been subjected to critical examination by the British Oxygen Co.[13] The rightward method turned out to be 30% less expensive than the leftward for $^1/_2$-inch mild steel (60° V instead of 80° V), but there is a steeper temperature gradient in rightward welding than in leftward. Mild steel 1 inch thick can be rightward welded at the rate of 2.0 to 2.5 ft./hr.

A brief description in *Engineering*[14] of the rightward welding of pipe by means of a multi-flame torch, using a special rod with deoxidizing agents states that the main flame is directed on the rod rather than on the plate, and is reducing, so yielding a carburized film of low melting point. The rod must be rotated to keep a point on the melting end, and rod and torch are given an accordion motion. A metallographic study of Keel's[15] "activated" oxyacetylene welding, which is featured by a rod containing 0.27 C, 0.80 Mn, 0.25 Si, 0.20 Al, is accompanied by a discussion of the thermo-chemistry of oxyacetylene welding. Instructions for the oxyacetylene welding of sheet metal are given by Bainbridge,[16] who considers it bad practice to apply flux by dipping the hot end of the rod in flux. He has prepared a table of blowpipe power for steel, copper, aluminum and Monel metal. In a conscientious manner Kohrs[17] shows what defects the oxyacetylene welder may make without being aware of them. *Industry and Welding*[18] describe jigs and preheating equipment for oxyacetylene welding, and Clark[19] illustrates an adjustable jig for oxyacetylene welding steel or copper pipes in line or at any angle.

The familiar firing-line and storm-gang methods of field welding pipe lines by the oxyacetylene process has been replaced to a great extent by the all-bell-hole method. In the stab-on variation of the all-bell-hole system, as Clark[20] points out, every weld is made over the ditch by a single welder, without turning the pipe. In stove-piping the joints are tack welded as they are lined up, and from two to eight welders follow in behind and make the weld in position.

Equipment for oxyacetylene welding does not appear to have undergone much development. Kemper's[21] description of gas welding exhibits at the Leipzig Fair in 1937 shows that innovations were confined largely to cutting and surface hardening devices. A torch with an air-acetylene flame surrounding the oxyacetylene welding flame is considered necessary by Trunschitz[22] for the leftward welding of nickel sheet (below 0.08 inch thick), which cannot be rightward welded. The injector action of the flame in left-hand welding draws air over the fluid nickel, the welds, therefore, being porous. The air-acetylene envelope provided by the new torch prevents porosity due to access of air to the liquid metal.

Urging the advantages of acetylene generators over tank gas, Mathy[23] states that acetone in the torch gas is detrimental to the weld metal. Generators are available which deliver acetylene at pressures up to 15 lb./in.^{2} The ratio of oxygen to acetylene can be maintained more nearly unity with generator acetylene than with tank acetylene, according to Magloire.[24] Acetylene generators are used to a much greater extent in European countries than in our own. Consequently the large number of foreign articles on generator construction, testing, operation and efficiency need not be discussed here. Oxyacetylene welding accounted for 20% of the 1936 consumption of calcium carbide in Germany.[25]

The mechanical properties and microstructure of oxyacetylene welds in low-alloy steel boiler plate (0.12 C, 0.80 Mn, 0.24 Si; and 0.13 C, 1.19 Mn, 0.18 Si, 0.15 Mo, 0.10 Cu) were excellent in Czternasty's[26] tests. Exhaustive tests of the tensile, roller bend, quench bend and notch-impact value of oxyacetylene welded low-carbon steel for liquid propane and butane cylinders made by Christmann[28] were entirely successful. A hydrostatic test to destruction (with stress-strain curves) of an oxyacetylene welded mild steel tank 4 ft. long showed that there was no danger in allowing design factors up to 0.9. The mechanical properties of welds in plain carbon steel (0.05 and 0.12% C, 0.08 to 0.63 inch thick) have been determined by Krause[27] as a function of excess oxygen and of additions of illuminating gas to the acetylene. Mecleary[31] recommends the air-acetylene torch for applying body solder to damaged auto bodies.

A paper on the atomic hydrogen process in general and an automatic atomic hydrogen welding head in particular has been prepared by Kurschner.[29] An automatic atomic hydrogen welding outfit for mild steel pipe 0.32-inch wall, using 70 amp. at a speed of 72 ft./hr. is described by Chistyakov,[30] who found that the welds had excellent mechanical properties. Garrison[32] claims that two Philadelphia gentlemen were the discoverers of the Thermit reaction in 1892.

REFERENCES (GAS WELDING)

1. Slottman, G. V., American Welding Society Journal, **16** (2) 9–13, Feb. 1937.
2. Ribaud, G., *Zeit. Schweisstechnik*, **27** (11) 208–214, Nov. 1937; *Chaleur et Ind.*, **18** (207) 301–302, July 1937.
3. David, W. T., *Phil. Mag.*, Ser. 7, **23**, 251–256 (1937).
4. von Elbe, G., and Lewis, B., *Amer. Chem. Soc. Jnl.*, **59** (4) 656–662, April 1937.
5. Stursberg, E., *Autog. Metallb.*, **30** (21) 353–361, Nov. 1, 1937.
6. Mies, O., *Autog. Metallb.*, **30** (2) 17–20, Jan. 15, 1937.
7. Trunschitz, —, *Autogenschw.*, **10** (2) 23–25; (3) 35 (1937).
8. Anon., *Soudeur-Coupeur*, **12** (2) Feb. 1937.
9. Anon., *Ind. Gases*, **18** (2) 81–83 (1937).
10. Bainbridge, C. G., *Welding Ind.*, **5** (1) 8–11, Feb. 1937.
11. Meslier, R., *Rev. Soud. Autog.*, **29** (276) 51–54, March 1937.
12. Thiesen, J. J., *Autog. Metallb.*, **30** (3) 37–38, Feb. 1, 1937.
13. Anon., *Aluminium & N. F. Rev.*, **2** (7) 263–268, May 1937.
14. Anon., *Engineering*, **144** (3732) 107, July 23, 1937; *Mech. World*, **102** (2659) 603–605, Dec. 17, 1937.

15. Keel, C. F., *Zeit. Schweisstechnik*, **27** (9) 168–176; (11) 208–214, Nov. 1937; translation will be sent on request.
16. Bainbridge, C. G., AMERICAN WELDING SOCIETY JOURNAL, **16** (4) 14–17, April 1937.
17. Kohrs, K., *Autog. Metallb.*, **30** (13) 213–219; (14) 241–252, July 1937.
18. Anon., *Ind. & Weld.*, **10** (1) 24–30, Jan. 1937.
19. Clark, F., *Welding Inds.*, **5** (7) 228–230, Aug. 1937.
20. Clark, S. C., *Petroleum Engr.*, **8** (10) 76, 79, Midyear 1937; Anon., *Oil & Gas Jnl.*, **36** (18) 205, Sept. 16, 1937.
21. Kemper, H., *Autog. Metallb.*, **30** (8) 114–123, April 15, 1937.
22. Trunschitz, L., *Autogenschw.*, **10** (5/6) 60–61, June 1937.
23. Mathy, E. L., *Western Machy. & Steel World*, 410–413, Nov. 1937.
24. Magloire, R., *Chaleur et Ind.*, **18** (208) 345–347, Aug. 1937.
25. Nicodemus, O., *Wiss. u. Techn.*, **41** (1) 5–8 (1937).
26. Czternasty, —, *Autog. Metallb.*, **30** (20) 337–346, Oct. 1937.
27. Krause, J., *Verwendung des Leuchigases in der Gasschmelzschweissung*; Dr. Ing. Disss. Technical College, Hanover, Germany. Published by H. Vogelsang, Bremen, 48 pages, 1937.
28. Christmann, N., *Zeit. Bay. Rev. Ver.*, **14** (13) 117–119; (14) 131–135, July 1937.
29. Kurschner, —, *Werkstattstechnik u. Werksleiter*, (1) 13–15, Jan. 1, 1937.
30. Chistyakov, N. V., *Aviog. Delo*, **8** (9) 20–23, Sept. 1937.
31. Mecleary, E. R., AMERICAN WELDING SOCIETY JOURNAL, **16** (9) 23, Sept. 1937.
32. Garrison, F. L., *Jnl. Franklin Inst.*, **223** (6) 779–784, June 1937.

APPENDIX VIII

Non-Destructive Tests for Welds

A brief review of 98 references to recent literature on non-destructive testing has been prepared by Vaupel,[1] who has also described the equipment of the new German National X-Ray Institute in Berlin.[2] The most important recent development at the Institute is the hollow anode tube, but apparatus for magnetic powder and magneto-inductive (for wire rope) methods is also installed, as well as a back reflection X-ray set-up for shrinkage stresses in welded pipe. The Institute has a traveling X-ray film development room for X-ray inspection of field welded plate girders. Vaupel reproduces a useful safety chart showing the distribution of scattered X-ray radiation back of a steel plate, and concludes that the only connection between the strength of welds and the results of any form of non-destructive testing is that based on experience. An elementary discussion of all forms of non-destructive tests for welds is given by Rollason.[3] Schmid[4] presents a cost comparison among X-ray, Gamma-ray and magnetic testing methods. Several writers have expressed the opinion that manufacturers of X-ray sets must develop means of visual inspection of welded structures by means of X-ray as in medical practice.

X-Ray Methods

The X-ray inspector can find no recent better guide to the interpretation of X-ray films of welds than the long paper by Pullin,[5] who emphasizes the importance of expert interpretation of X-ray films. The ground density in a correctly exposed radiograph should be between 0.8 and 1.0 H. & D. in order to reduce as far as possible the effect of increasing thickness in masking a defect of given dimensions. The visibility of a hole in a plate is shown to decrease as the diameter of the hole is decreased; similarly the visibility of a wire on the surface decreases as the length of the wire decreases, the hole and wire having constant depth and diameter, respectively. A penetrameter (long wires or plate with holes of large diameter) should detect defects larger than 1% of the thickness in welds up to 2 inches thick, and 2% for thicker plates. Pullin describes a reference frame for use in locating defects with the aid of a penetrameter. The Potter-Bucky diaphragm increases the time of exposure six fold but is essential for thick welds.

The radiograph's appearance is fairly well related to specific gravity but welds having a specific gravity of 7.80 may still show flaws in the X-ray. Slag inclusions show in the X-ray generally as angular patches with more or less straight edges parallel to the scarves, whereas gas inclusions are rounded. Cracks usually occur, if present, at the base of a V weld and may be charted by moving the target. In general, 150 kv. is correct for welds in steel 1 inch thick, 220 for 2 inches and 260 for 3 inches.

In the hollow anode tube (up to 150 kv.) for fillet welds and some types of welded vessels, as described by Müller,[6] the target is outside the tube proper in a slender extension tube lined with gold foil. Since the tube-film distance may be as small as 2 inches only a small section of a flat weld may be registered at one exposure. A so-called "dot" method has been developed therefore in which a long film is used and the tube is moved along the weld between exposures in steps equal to the length of film affected in one exposure.

Müller's earlier research[7] established the relation

$$\frac{t_2}{t_1} = \left(\frac{R_2}{R_1}\right)^{5/2} = \left(\frac{i_1}{i_2}\right)^{5/4}$$

among time of exposure t, tube-film distance R and filament current i. He also prepared a nomograph for steel welds relating thickness (up to 4 inches), density of metal, tube voltage (80 to 200 kv.), intensifying screen constant, tube-film distance (1.2 to 8 inches), ratio of film diameter to tube-film distance, and time of exposure (20 sec. to 1 hr.). With 200 kv. the practical limit for steel is $2^3/_4$ inches. Müller condemns wire pen trameters and prefers instead, a stack of plates with artificial inclusions of a paste composed of iron filings and wax.

Before an attempt is made to chisel out a flaw in a weld shown by X-ray, Collender's[8] advice to prepare a stereo-photo should be kept in mind. Two pictures are recorded on the same film, the angle of radiation being shifted 60° between shots. A lead arrow is placed on the near side of the weld and another on the far side to serve as reference marks. The depth of the flaw can be predicted to within $^1/_{16}$ inch. Four welded pressure vessels with sound seams as judged by X-ray were subjected to a fatigue test (cycles from zero to 1100 lb./in.^{2}, 6 cycles per minute), which resulted in cracks in the heads at a distance from the welds at a fiber stress of 18,000 lb./in.^{2}

The portable X-ray unit is becoming a necessity for the welding inspector. Isenburger[9] describes a portable X-ray outfit for field welded pressure piping, and Morrison and Angus[10] illustrate the use of a similar outfit of 220 kv. capacity, which, it is said, can penetrate 3 inches of steel in 1 minute. Two films are made at each point, one for each of two positions of the tube on either side of the pipe. Six pairs of exposures are made for each joint in 12-inch pipe. A French writer[11] mentions a portable set for inspecting welds in ship plating while the ship is on the ways. A sensitivity of 1% of the thickness is attained. A portable unit 250 kv., 310 lb. total weight is used by Swedish bridge inspectors[12] together with a traveling film development room for field welded girders at temperatures as low as −18° C. Excellent reproductions show that nearly 30% of the field welds needed repair (0.63 to 2.35 inches thick). Steenbergen[13] describes a portable X-ray outfit for welded pressure vessels (200 kv., 8 *m A*). A weld 0.79 inch thick, $16^1/_2$ ft. long is X-rayed in 10 sections, 20 inches tube-film distance, 120 kv. A thickness of 2 inches of steel requires an exposure of 3 minutes at 160 kv. for 0.5 blackening, using a tube-film distance of 16 inches, 4 *m A*, and Agfa special film with 2 Gehler foils for hard radiation. The field is 2.6 x 2.6 inches.

Best results are obtained in X-raying welded clusters of aircraft tubing, according to Petiniaud,[14] with a filter equivalent in opacity to the thickest section to be X-rayed. The filter, which may be tin or copper, is placed directly in front of the film. Charts are presented to show that for steel, 1 inch total thickness, 150 kv. should be used with a copper filter, $^1/_2$ inch thick. For 1 inch of aluminum the copper filter should be 0.06 inch thick at 50 to 60 kv. An enthusiastic believer[15] in X-ray examination as a means of improving the quality of welding has prepared an album of radiographs of welds which shows the bad effect of moisture in the electrode coating on porosity as well as the pipe which may be formed at the end of a weld and is caused by not playing the arc or torch long enough on the molten pool. Bonhomme[16] particularly recommends the X-raying of butt welds with the beam directed along the angle of the scarves. Nevertheless he is convinced that "pasting" is beyond the power of the X-ray to detect.

In a review of X-ray practice in England, Dorey[17] points out that the penetrameter method (2% sensitivity) has been adopted by Lloyds for welded boilers and that films, screens and tubes are the variables at the present time. He illustrates an unusual transverse crack in a butt weld in steel revealed by X-ray. X-ray practice for welded joints in Japan is outlined by Nakamura-Hazime,[18] who emphasizes the importance on the part of the X-ray inspector of a thorough grasp of photography. An unusual application of X-rays to the detection of defects in the soldering of gold plate (a thin sheet of gold soldered face to face to a thick sheet of copper) is illustrated by Wrighton and Jarrett.[19] Nelson[31] states that the limiting thickness for the use of Gamma rays for steel welds is 10 inches.

It is known that shrinkage stresses are inherent in most welded structures that have not been stress relieved by thermal or mechanical treatment and that the magnitude and distribution of the shrinkage stresses are sensitive to such slight changes in welding and cooling procedure as may reasonably be expected in any manual operation. Yet discouragingly little progress has been made in developing the only non-destructive methods of measuring shrinkage stresses that bears any promise: namely, the X-ray methods. Two methods have received attention recently. The line-breadth method has been studied by Norton[20] and the parameter method by Möller and Roth.[21]

Norton uses the half breadth of the K-alpha one line as the criterion of shrinkage stress, the greater the stress, the broader the line. As the stress-relieving temperature of a weld in mild steel $^1/_2$ inch thick was raised from 400 to 650° C., the half breadth decreased from 0.6 to 0.3. The line breadth method is useful for comparative purposes, whereas the parameter method used by Möller and Roth measures the shrinkage stress in absolute value. Using the Rose modification of the Seemann-Bohlin apparatus and exposures of 20 to 30 seconds with cobalt radiation, Möller and Roth found that the shrinkage stresses in gas welded Cr-Mo tubing in rigid triangular arrangement amounted to as high as 62,500 lb./in.^{2} tension in the weld metal and up to ±54,000 lb./in.^{2} in base metal. With steel the accuracy is 1 x 10^{-4} Å but the surface must be etched to a depth of 0.004 inch to avoid spurious effects. Regler[22] reports having used a portable X-ray tube with success in studying the crystal structure of old bridge members in order to judge their state of fatigue. His work has an obvious application to welds.

Magnetic Methods

Practice in this country in the use of the magnaflux method for welded pressure vessels and boiler fittings is summarized by Cavanagh and Yant.[23] The comparatively low sensitivity and field of application of the A.C. magnetic test with oscillograph has been demonstrated Kouwenhoven and Vivell,[24] who have demonstrated the value of their laminated specimen for estimating the sensitivity of any non-destructive test. Günther[25] gives a brief description of a portable D.C. magnetic tester for sections up to 4.7 sq. in., and a portable A.C. magnet (up to 1500 amp.) with adjustable poles for the ampere turns method of testing.

Another portable device for testing by the ampere turns method with the aid of the usual magnetic powder is recommended by Berthold and Gottfeld,[26] although the depth sensitivity is not great. The two electrodes are placed on the steel a few inches apart in the vicinity of the crack, and are particularly useful in confined spaces, such as in a chipped-out crack. The method apparently is used in conjunction with X-rays for ascertaining when a crack revealed by X-ray has been completely removed by the chisel, taking spreading of the crack into account.

The magnetic device for testing butt welds in boilers described by Tuczko[27] consists of three yokes parallel to each other and spanning the weld. The center yoke picks up the field created by the outer yokes. In Leonhardt's[28] magnetic test the welded plate is magnetized and a search coil is moved to and fro in short movements at a definite speed above the weld. Flaws appear as notes in an ear phone.

A brief account is given by an English writer[29] of two electrical methods for detecting flaws in welds. In one method three exploring contacts are connected to a primary coil (50 cycles A.C.) of which the secondary is connected to an amplifier. Flaws change the distribution of the current among the contacts as they are moved along the weld, and thus give rise to a change in tone at the amplifier. The second method involves three contacts as in the first, but D.C. is used and two millivoltmeters indicate the presence of defects in the weld.

Acoustic methods for detecting flaws are becoming more elaborate than the old steel-hammer-and-amplifier method. The method perfected by Hayes[30] is based on symmetrical Chladni sand patterns and their distortion by defects, which reduce the stiffness locally. The plate to be examined (1 foot diameter, or 5 ft. long by 1 ft. wide by $^9/_{16}$ inch thick) is the armature across the jaws of a magnet supplied with D.C. and A.C. from a tunable power tube generator (500 watts A.C. is sufficient to oscillate a plate 1 ft. wide of any length or thickness). Exact location of the defects either in depth or in area would be out of the question, but then the method is only recommended for detecting plates with laminations that are injurious to fusion welding. An anonymous writer[29] briefly describes a method for detecting defective welds which depends on the fact that supersonic waves are reflected by flaws.

REFERENCES (NON-DESTRUCTIVE TESTS)

1. Vaupel, O., *Maschinenbau*, **16** (11/12) 320–321, June 1937.
2. Vaupel, O., *Chem. Apparatur*, **24** (9) 141–145, May 10, 1937.
3. Rollason, E. C., *Welder*, **9** (New Series) (38) 6–11, 25, Jan. 1937.
4. Schmid, E., *Maschinenbau*, **16** (5/6) 149–152, (19/20) 519–522 (1937).
5. Pullin, V. E., *Welding Ind.*, **5** (3) 104–114, April 1937.
6. Müller, E. A. W., *Arch. Eisenhüttenwes.*, **10** (10) 481–483, April 1937.
7. Müller, E. A. W., *ibid.*, **10** (6) 267–273, Dec. 1937.
8. Collender, K. G. F., *Trans. South African Instr. Engrs.*, **28** (5) 109–134, May 1937.
9. Isenburger, H. R., *Welder*, **9** (New Series) (43) 165–167, 173, June 1937.
10. Morrison, W. S., and Angus, W. J., *Power*, **81** (9) 480–483, Sept. 1937.
11. Anon., *La Metallurgie*, **69**, 11–17, Jan. 2, 1937.
12. Sabelstrom, S., *Teknisk Tidskrift*, **67** (VII) 121–128, Nov. 27, 1937.
13. Steenbergen, B. V., *Laschtechniek*, **3** (3) 32–35 (4) 49–50, 52–56 (1937).
14. Petiniaud, A., and Schmidt, R., *L'Aéronautique*, **19** (212) 3–8, Jan. 1937.
15. Sandstede, K., *Wärme*, **60** (45) 737–741, Nov. 6, 1937.
16. Bonhomme, W., *Tech. Soud. Decoupage*, (33) 601–610, Jan.–Feb. 1937.
17. Dorey, S. F., *Jnl. I. Civil E.*, (7) 621–666, June 1937; *De Ingenieur*, **52** (48) W141–W142, Nov. 26, 1937.

18. Nakamura-Hazime, *Shibaura Review*, **16** (10) 401–408, Oct. 1937.
19. Wrighton, W. J., and Jarrett, T. C., *Metals and Alloys*, **8** (3) 78–79, March 1937.
20. Norton, J. T., AMERICAN WELDING SOCIETY JOURNAL, **16** (10) Research Supplement, 19–22, Oct. 1937.
21. Möller, H., and Roth, A., *Mitt. KWI Eisenfschg.*, **19** (10) 127–130 (1937).
22. Regler, F., *Zeit. Elektrochem.*, **43** (8) 546–556, Aug. 1937.
23. Cavanagh, R. F., AMERICAN WELDING SOCIETY JOURNAL, **16** (4) 28–30, April 1937; Yant, J. W., *ibid.*, **16** (1) 5–7, Jan. 1937.
24. Kouwenhoven, W. B., and Vivell, A. E., *ibid.*, **16** (10) Research Suppl., 47–50, Oct. 1937.
25. Günther, H., *Elektroschwg.*, **8** (4) 68, April 1937.
26. Berthold, R., and Gottfeld, F., *Stahlbau*, **10** (4) 31–32, Feb. 12, 1937.
27. Tuczko, K., *Technika Cieplna*, **15** (6/7) 85–89, July 1937.
28. Leonhardt, R. W. P., *Modern Machine Shop*, **10** (2) 68–74, July 1937.
29. Anon., *Mech. World & Engg. Record*, **102** (2636) 27, 30, July 9, 1937.
30. Hayes, H. C., *Jnl. Acoustical Soc. America*, **8**, 220–226 (1937).
31. Nelson, W. L., *Oil & Gas Jnl.*, **36** (9) 71–72, July 15, 1937.

APPENDIX IX

Hard Facing and Flame Heat Treatment

Special Hard Alloys

Aside from practical instructions and glowing claims, the literature yields little information on hard facing. M. C. Smith[1] is correct in pointing out that abrasion resistant alloys have not been developed to the same extent as corrosion resistant alloys from the standpoint of ability to resist weight loss. He briefly describes a cast-on process of overlay with nickel boride alloy, the contrifugal principal being employed for lining tubes. Step-by-step instructions for stelliting are given by Le Van[2] and others.[3] These are well known; a flame with excess acetylene is used and the rod is always kept on the work. Cast iron is more difficult to stellite than steel.

The Oxyacetylene Committee Report on Hard Facing is reprinted by *Industry & Welding*,[4] according to which plain-carbon and low-alloy steels, cast-iron and Monel metal are readily hard faced. The thickness of the deposit usually varies from $^1/_{16}$ to $^1/_4$ inch. The maximum wear resistance of tungsten carbide inserts is said to be secured by coating the crushed carbides with a steel binder deposited over the inserts. Possibly this statement requires modification depending upon the particular service conditions involved. In Le Van's[5] general review of progress in hard facing it is emphasized that the good wearing characteristics of cobalt-chromium-tungsten hard-facing alloys is due to their high hardness *at working temperatures*. The instructions given by a French welder[6] for stelliting marine Diesel valves involve using a flame with excess acetylene (acetylene cone 3 times as long as center cone) and the torch is held at an angle of 30 to 60° to the surface before applying the rod. Again, these are the usual instructions. Stalinite,[7] a Russian hard-facing alloy for stone drills, contains 21% Cr, 42% Fe, 18% Mn, 8% C, 1% Si; the remainder is tar used for extruding the alloy as an electrode. An Australian discovery is Cobalide,[8] the composition of which is kept a complete secret by the makers. Apparently a hard carbide or the like, Cobalide is selfhardening to 650 Brinell and is deposited by oxyacetylene torch.

Building Up Rails

The building up of rails and crossings is an important application of surfacing by welding. Complete instructions for the resurfacing of railroad crossings by means of the oxyacetylene torch with backhand technique and a three-jet torch are given by Swinnerton.[9] Frankenbusch[10] provides similar practical details on the oxyacetylene surfacing of rails in Germany. According to Hartley,[11] who describes the building up of rail ends with the oxyacetylene torch, the heat should not penetrate more than one half the depth of the railhead if difficulties are to be avoided. A summary of present rail hard-facing practice in Germany is given by Kessner and Kalberlah.[12] The metal arc process for building up rail ends requires preheating, Daley[13] states, otherwise cracks will be found. Instead of hard facing the worn grooves of trolley rail frogs, Kruger[14] recommends the welding of wear-resistant steel inserts into the groove.

Wear tests in the Amsler machine (pure sliding friction, 9 ft./sec., 270 lb./in.^{2} surface pressure, total distance of 29,400 ft.) against a disk of material having very high wear resistance were made by Sauermann[15] on deposits laid down by the following electrodes: (*a*) 0.59% C; (*b*) 1.02% C; (*c*) 1.15% C, 16.0 Mn; (*d*) 1.01% C, 0.30 Mn, 0.92 Cr, 1.60 W. Deposits made by (*c*) and (*d*) had the highest wear resistance, although (*b*) was better than (*a*). Annealing increased the wear resistance of (*b*). Peening increased the wear resistance of all, but hardening decreased the wear resistance, and tempering failed to raise the resistance to the level of the annealed deposits. There was no connection between wear resistance and hardness. Decreasing the velocity by 50% slightly decreased the amount of wear. Deposits on water-cooled specimens gave low, irregular results. For as-welded deposits (not for heat-treated) the temperature of the wearing surfaces increased with increasing wear resistance. Wear by abrasive materials could not be correlated in any way with wear by sliding friction. Burjak[16] found that deposits laid down by two types of coated electrodes had three times the wear resistance of plain carbon rail steel. The coating of one electrode contained 75% ferro-manganese, the other 75% ferro-chromium, mixed with 15% graphite and 10% lime, all mixed with a binder of 2 parts water, 1 part waterglass, so that the coating was 0.040 inch thick on $^1/_8$-inch electrodes (100–130 amp.) and 0.075 inch thick on $^1/_4$-inch electrodes (220–250 amp.). The deposit laid down by the Fe-Mn electrode was 212–293 Brinell in one layer, 228–460 Brinell in two layers; that of the Fe-Cr deposit was 387–532 Brinell, whether in one or two layers.

General

Kohrs[17] refers briefly to tests showing that surface welding on shafts may lead to fatigue failure, but states that the surface deposition of steel and copper alloys is established practice in Germany. At Fort Peck Dam surface welding by the metal arc process (no details) and welded chromium cast-iron inserts on impellers and liners, respectively, were decidedly instrumental in prolonging the life of the dredge pumps.[18] The bronze surfacing of eroded spots on cast iron and steel hydraulic turbine runners in position, using the oxyacetylene torch and flux, is explained by Meslier.[19] The beads are deposited radially in straight runs from the outside toward the center. About 1 lb. bronze per hour may be deposited. In surfacing worn spots on boilers, according to Frantz,[20] the beads should be deposited in short lengths in squares, the direction of the beads being at right angles in adjoining squares. Deposits should not be machined flush because the as-welded surface has the best corrosion resistance. Popok[21] describes the cold surface welding of worn cast-iron rolls using the carbon arc, 180–200 amp. D.C. The filler rod ($^7/_8$ inch diameter) should contain 2.5% total C, 1.4% combined C, 5.8% Si, 0.14 Mn, 0.22 Ni, 0.06 S, 0.04–0.05 P. Although the surfacing of locomotive throttle lever guides is a small job, it requires care, as pointed out by Fiedler.[34] The guide is surfaced in a water bath with a wear-resisting steel electrode using a copper backing strip.

Flame Heat Treatment

Any one not familiar with the wide field of application of manual and machine surface heat treatment with the oxyacetylene torch should read Seeman's[22] summary. The usual depth of heat treatment is $^1/_{16}$ to $^1/_4$ inch. All S.A.E. steels above 0.35% C (preferable 0.40–0.70% C, S.A.E. 6100 series being particularly good) and many others may be treated. The spinning and progressive methods are combined for large cylindrical surfaces. To harden 4 sq.in. of steel requires 1 cu.ft. each of oxygen and acetylene. The properties of surface heat-treated parts have been determined by Kallen and Nienhaus.[23] Bending, torsion and bearing temperature tests (incomplete details) on flame heat-treated axles of shallow and deep hardening steels were entirely satisfactory. It was found that when the temperature of the surface of a plain carbon shaft 4 inches diameter was 850° C., the temperature at the center was 300–370° C. when preheating was not used. Multi-flame heads for flame-softening flame cut surfaces in higher carbon and alloy steels (e.g., S.A.E. 1040) are described by Moss.[33]

The remainder of the recent literature on surface heat treatment is of a general nature. Results and machines, together with thirty good micrographs, are described by Dehasse.[24] German developments are discussed by Eberle[25] and Prytz.[26] They parallel to a great extent developments in this country, as summarized by Sykes.[27] According to Eberle, the most suitable steel for surface hardening contains 0.45% C; 58 C Rockwell is attainable. An increase in Mn to 1.2% will displace the minimum carbon content for good hardening below 0.35%. Minimum depths of hardening are 0.059 inch for shafts 1.18 inches diameter, and 0.18 inch for shafts 6 inches diameter. Flame-hardened parts in steel containing 12% Cr, 1.6% C have been successful, according to Prytz. Sykes' machine for torch hardening gears may be applied up to 6 diametral pitch. Too rapid and too high heating with too rapid quenching produces a sharp line of demarcation between soft and hard zones, which is also observed when the heating flame is completely surrounded by water, although in the latter event the hardened surface is free from color or previous rust.

Flame hardening applied to internal, as well as external threads and gears (0.40–0.50% C, 1.60–1.90% Mn) is dealt with by Rolf.[28] Dies after service must be annealed before flame hardening to avoid checks (no explanation). According to Lindberg,[29] fine grained gear steels (0.40–0.70% C) are easier to flame harden than coarse grained; vanadium steels are especially good. Heads with multiple tips are often used to secure uniform heating. Details and cost analyses of the local hardening of scissor dies with the hand torch are supplied by Ruck.[30] The hardening penetrates only $^1/_5$ of the total thickness (0.6–0.9% C steel, low Mn), avoids the usual hardening cracks, and produces an almost structureless martensite adequate to withstand hammer blows of 3.250 ft.-lb.

Possibilities for surface heat treatment with the arc are good, as MacFarland[31] points out, but few applications have been made. Bronson's[32] reason for the little use made of the arc in heat treating rail ends is that the process, which consists of preheating, playing the arc, and oil quenching, is too difficult to control.

REFERENCES
(HARD-FACING AND FLAME HEAT TREATMENT)

1. Smith, M. C., *American Machinist*, **81** (10) 415–417, May 19, 1937; *Weld. Engr.*, **22** (2) 25–27, Feb. 1937; *Ind. & Weld.*, **10** (11) 24–28, Nov. 1937.
2. Le Van, E. E., American Welding Society Journal, **15** (4) 32–36, April 1937.
3. Henrion, E., *Bull. Tech. Union des Ing. Louvain*, (2) 33–36 (1937); Anon., *Spawanie i ciecie Met.*, **10** (7) 137–144, July 1937; *Rev. Soud. Autog.*, **29** (278) 98–101, May 1937.
4. Anon., *Ind. & Weld.*, **10** (2) 16–22, 44–45, Feb. 1937.
5. Le Van, E. E., *Metals & Alloys*, **8** (7) 206–209, July 1937.
6. Anon., *Soudeur-Couper*, **12** (7) 4–9, Aug.-Sept. 1937.
7. Krenov, K. K., and Evseev, G. B., *Avtog. Delo*, **8** (7) 20–22, July 1937.
8. Anon., *Modern Engr.*, **11** (8) 432–434, Aug. 1937.
9. Swinnerton, N. W., *Weld. Ind.*, **5** (5) 180–188, June 1937
10. Frankenbusch, H., *Autog. Metallbearbeit.*, **30** (6) 81–87, Mar. 15, 1937.
11. Hartley, J. G., American Welding Society Journal, **16** (4) 7–10, April 1937.
12. Kessner, —, and Kalberlah, —, *Gleistechn.*, (17/18) 165–170 (1937).
13. Daley, C. A., American Welding Society Journal, **16** (3) 7, March 1937.
14. Kruger, G., *Verkehrstechnik*, **18** (17) 403–408, Sept. 5, 1937.
15. Sauermann, W., *Über Verschleissuntersuchungen an Auftragschweissungen*: Diss. Techn. Hochsch. Danzig, published by Studentwerk, Berlin-Charlottenburg, 27 pages, 1937.
16. Burjak, J. W., *Avtog. Delo*, **8** (7) 22–27, July 1937.
17. Kohrs, K., *Maschinenschaden*, **14** (10) 157–162 (1937).
18. Jefferson, T. B., American Welding Society Journal, **16** (10) 5–12, Oct. 1937; *Engg. News Rec.*, **119** (23) 896–900, Dec. 2, 1937.
19. Meslier, R., *Rev. Soud. Autog.*, **29** (284) 247–249, Nov. 1937.
20. Frantz, G., *Wärme*, **60** (36) 582–583, Sept. 4, 1937.
21. Popok, D. P., *Avtog. Delo*, **8** (2) 39–40, Feb. 1937.
22. Seeman, K., *Metal Progress*, **32** (3) 247–251, Sept. 1937.
23. Kallen, H., and Nienhaus, H., *Glasers Annalen*, **121** (2) 45–48, July 15, 1937.
24. Dehasse, C., *Rev. Univ. Mines*, Series 8, **13** (6) 237–248, June 1937.
25. Eberle, W., *Engg. Progress*, **18** (9) 205–208, Sept. 1937; *Maschinenbau*, **16** (7/8) 203–205; (9/10) 257–259 (1937).
26. Prytz, C. E., *Teknisk Tidskrift*, **67**, Mekanik (10) 133–136; (11) 142–144, Oct., Nov. 1937.
27. Sykes, W. E., *Machinery* (N. Y.) **44** (3) 196–198, Nov. 1937; *American Machinist*, **81** (22) 1034–1037, Nov. 3, 1937.
28. Rolf, R. L., *Steel*, **101** (18) 48–51, Nov. 1, 1937.
29. Lindberg, L. A., *Weld. Engr.*, **22** (9) 37–39, Sept. 1937.
30. Ruck, E., *Werkzeugmaschine*, **41** (10) 234–237, May 1937.
31. MacFarland, A. M., *Weld. Engr.*, **22** (4) 33, April 1937.
32. Bronson, C. B., American Welding Society Journal, **16** (1) 12–13, Jan. 1937.
33. Moss, H. H., *Iron Age*, **140** (27) 22–30, Dec. 30, 1937.
34. Fiedler, —, *Bahn-Ingenieur*, (42) 662, Oct. 1937.

APPENDIX X

Arc Welding Generators and Transformers

A well-balanced, elementary explanation of the characteristics of shunt and series-wound generators is given by Osborne.[1] A more detailed and mathematical discussion based on oscillograms is given by Dreyfus,[2] who derives expressions for efficiency and static and dynamic characteristics of compound wound, cross field and two-pole types of welding generators. Instead of using the oscillogram directly as the so-called dynamic characteristic of a generator, Humburg[3] plots the maximum swing of current or voltage on the opposite side of the static characteristic, which is caused by the inertia of the generator. The steeper the dynamic characteristic determined in this manner, which is found experimentally to be practically straight for the usual machines, the less is the current surge on short circuit, and the less tendency there is for the arc to be extinguished during globule transfer. Tests of seven different commercial generators by Haas and Scheuring[4] showed a wide scatter between motor rating, generator voltage and welding current. Nevertheless, they believe there is a possibility that the large number of existing types of generators may be reduced to 5, or at most 8 types by judicious standardization. Frazier[5] found that the depth of penetration of beads of bare and coated steel electrodes is quite independent of the slope of the static characteristic of the generator.

In De Lange's[6] opinion the two requirements of a welding generator are a steep static characteristic, that is, the current does not change greatly as the arc is lengthened, and a quick response to sudden changes in arc resistance caused by globule transfer. He agrees with the A.I.E.E. definition of time of recovery as the time elapsed between the breaking of short circuit and attaining half no-load voltage. A dual-current machine (140 amp. D.C., 300 amp. A.C.), which De Lange describes, employs a rectifying tube of the oxide-coated cathode type. The voltage rises from short circuit value to open-circuit value in 0.002 sec. In a cross field generator with interpoles and large leakage flux for voltage regulation, described in *Engineer*,[7] the voltage rises to 110 volts in 0.0314 sec. after short circuit from an open-circuit value of 35 volts,

the short circuit current being 305 amp. In France[8] two points of view are said to prevail among makers of welding generators. One places most importance on shortness of time to re-establish arc voltage after rupture of short circuit (0.002 sec. with thyratrons). The other stresses high voltage at the striking of an arc (60% above static value) and permits a recovery period of 0.008 sec. Designing a drooping characteristic generator to improve the excitation response for stabilization is better, according to Bayles,[22] than using series reactance, which always retards the initial current rise and produces large inductive kicks at break without materially assisting field recovery. Trissal[23] gives a good description of a lightweight two-pole series excited generator. An adjustable air gap controls the current and instead of overshoot on short circuit there is undershoot.

The arc-welding installation at Penhoët shipyard, France, of Normandie fame, totals 20,000 amp. D.C. generated from 5000 volts A.C. (to 40 volts D.C. by 2000 amp. and 4000 amp. converters as Faerman[9] explains; 665,000 kwh. was consumed in 1936 at Penhoët. Reactance rheostats are used for each welder. Faerman gives a detailed description of the Brown-Boveri high-speed current and voltage regulator (magnetic principle) for central welding stations.

The relative advantages and disadvantages of multi-operator installations have been debated by a number of foreign writers. An unprejudiced review is given by Salelles,[10] who explains in detail the following methods of distributing welding current to a number of welders. Static methods: rheostats, reactances, self-regulating transformers, transformers with regulating inductance, special transformers for balancing load on phases or for high power factor, and tube rectifiers. Dynamic methods are: self-regulating generators, generators with constant secondary voltage and regulating resistances, and engine-driven generators. Salelles wisely refrains from drawing any conclusion because each installation requires special consideration. A similar discussion is given by Higgins[11] who rather fancies the multi-operator transformer. The average duty cycle for manual welding varies from 10 to 20% for sheet metal work to 35 to 50% for tank, bedplate and large girder work. The ratio of continuous rating to total connected load varies from 0.7 for 1 operator to 0.4 for 6 operators.

MacFarlane's[12] analysis of the current distribution situation is based on the Williamson chart, in which the "diversity factor" K is concerned

$$K = 1/(1 + log_{10}N)$$

where N = number of operators. The maximum current capacity of one arc multiplied by the diversity factor equals the continuous capacity of a multi-operator set. MacFarlane states that the level compound-wound generator with ballast resistances competes with the single self-regulating generator only when 4 arcs or more are supplied. Over 50% of English rotary type D.C. welders are motor driven, 30% belt driven, 10% engine driven. All things considered, Taton[13] finds that 500 amp. multi-operator sets are more economical for French shipyards than single operator sets. The generator voltage in the range 45 to 60 volts had no effect on tension, bend and notch-impact values of all-weld-metal. Beyond 60 volts the mechanical properties remain good but the electrode gets too hot; below 45 volts the properties rapidly become poor.

A great deal of debate has also raged around the relative desirability of A.C. compared with D.C. MacFarlane[12] shows that in England D.C. is much cheaper than A.C. for welding. For French shipyards, however, Volff[14] favors A.C., contrary to Taton.[13] The same number of welders should use each of three phases, a fourth wire serving as neutral and ground. The open circuit voltage between phase and neutral should be 65 to 75 volts. In one yard a synchronous motor with exciter maintains the power factor near unity. Comparing D.C. and A.C., Stieler[15] found that the efficiency of the transformer is higher than that of the generator but the efficiency is not so good unless a condenser is used. Spatter and velocity of melting were the same for both processes. An overpowering array of mechanical property data was amassed to prove that there is not an iota of difference between welds made by D.C. and A.C. Spaulding,[16] who also engages in the A.C.-D.C. debate, is of the opinion that the high-frequency variations in arc-welding resistance and temperature are the result of chemical reactions, such as the oxidation of iron, carbon and silicon, which constitute one of the two essential sources of arc heat, of which electrical energy is the greater part. He will not find many to agree with him.

Good welding transformers have 50% power factor, 80 to 90% efficiency, according to Staggs.[17] Series impedance is introduced to limit the short circuit secondary current to not over 110% of the welding current for which the welder is adjusted. The temperature at electrode and plate in A.C. arc welding of steel is 3200° C. Also Thomasson[18] refers to a welder with 100,000 cycle stabilizing current superimposed on 25 or 60 cycle A.C. to maintain the ionized condition of the arc gap and to provide extremely stable arcs even at 50 to 80 amp. Conditions in Germany are such that the transformer connected to one phase of the three phase supply is the best national policy, according to Thoma, Jacob and Werner.[19] Transformers create less disturbance than generators of the same capacity (170 to 250 amp.), it was found. Jacob points out that the nearer the transformer is to the power station the greater is the permissible welding load, a change of 2% in voltage (380 volt system) being just perceptible to the average lamp user. In country districts, sometimes, the transformer cannot be permitted.

Automatic arc welding is dealt with by Sarazin.[20] Fully automatic welding may be four times faster than manual. The Cuirasse automatic wire is wound with widely spaced wire; then coating is applied and wrapped with ribbon. The wire spiral serves to conduct current to the electrode. A single pass weld in $^1/_2$-inch plate can be made at 450–500 amp. at the rate of 33 feet per hour. An automatic carbon arc-welding head is described by Thiele[21] in which paper-covered wire is replaced by flux automatically spread on the scarves.

REFERENCES (GENERATORS AND TRANSFORMERS)

1. Osborne, S. C., AMERICAN WELDING SOCIETY JOURNAL, **16** (6) 11–15, June 1937.
2. Dreyfus, L., *Teknisk Tidskrift*, **67**, Elektrotekniek (1) 6–12; (2) 23–27, Jan., Feb. 1937.
3. Humburg, K., *Elektroschwg.*, 8 (6) 107–110; (8) 155 (1937).
4. Haas, K., and Scheuring, W., *ibid.*, **8** (11) 208–212, Nov. 1937.
5. Frazier, N., AMERICAN WELDING SOCIETY JOURNAL, **16** (11) 13–14, Nov. 1937.
6. De Lange, S. G. P., *Engr.*, **163**, 295–296 (1937).
7. Anon., *Engr.*, **163**, 670–671 (1937).
8. Anon., *Electricité*, **21** (29) 80, Feb. 1937.
9. Faerman, W. L., *Trans. Instn. Naval Archts.*, **79**, 306–320 (1937).
10. Salelles, R., *Rev. Soud. Autog.*, **29** (278) 102–108, May 1937.
11. Higgins, W. M., *Modern Engr.*, **11** (3) 149–152 (1937).
12. MacFarlane, J. W., *Sheet Metal Inds.*, **11** (125) 831–833; (126) 932–933 (1937).
13. Taton, J., *Bull. Tech. Bureau Veritas*, **19** (1) 7–13, Jan. 1937.
14. Volff, C., *Technique Moderne*, **29** (13) 470–475, July 1, 1937.
15. Stieler, C., *Elektroschwg.*, **8** (4) 61–63; (5) 88–92 (1937).
16. Spaulding, R. L., AMERICAN WELDING SOCIETY JOURNAL, **16** (8) 8–10, Aug. 1937.
17. Staggs, R. W., *Factory Management & Maintenance*, **95** (4) Part 1, 64–65, 96, April 1937.
18. Thomasson, H., *Engg. Jnl. Canada*, **20** (1) 8–14, Jan. 1937.
19. Thoma, R., *Elektrizitätswirtschaft*, **36** (26) 587–590, Sept. 15, 1937; Jacob, —, *ibid.*, 590–592; Werner, —, *ibid.*, 592–594.
20. Sarazin, R., *Bull. Tech. Bureau Veritas*, **19** (1) 31–36, Jan. 1937.
21. Thiele, A., *TZ prakt. Metallb.*, **47** (17/18) 692–694, Sept. 1937.
22. Bayles, J. W., *Electric Welding*, **7** (38) 54–58, Dec. 1937.
23. Trissal, J. M., *AREA Proc.*, **38**, 128–131 (1937).